

PRELIMINARY

Am386[®] DE

High Performance, Low Power, 32-Bit
Embedded Microprocessor



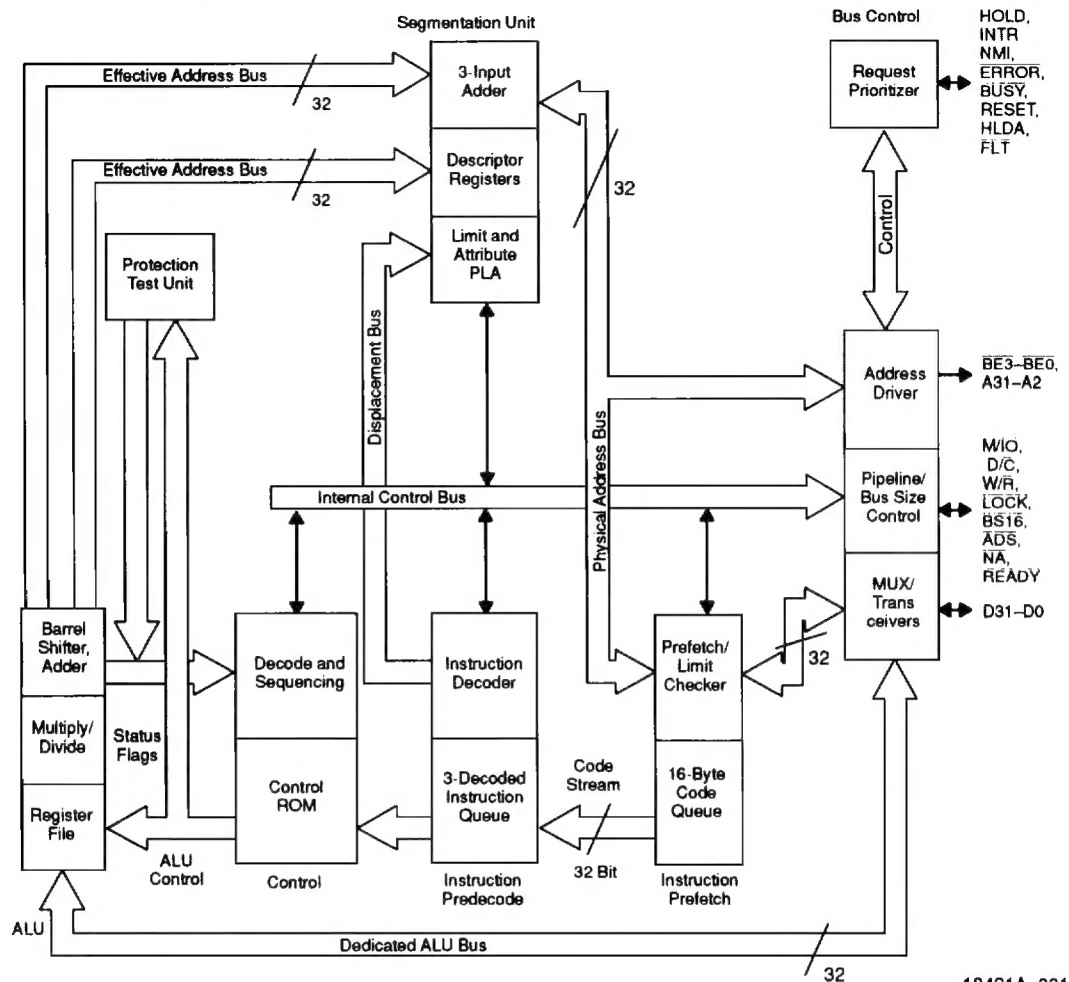
Advanced
Micro
Devices

DISTINCTIVE CHARACTERISTICS

- **Member of Am386 E CPU series**
 - Am386 microprocessor core
 - Designed for embedded applications
 - Socket compatible with 386DX processor
- **Industry standard architecture allows use of existing peripheral support chips, development tools, and application software**
- **Ideal for embedded applications**
 - Low power consumption
 - 3–5 V operation
 - Fully static operation
- **High performance**
 - 33-MHz operating frequency
 - 32-bit architecture
 - 30-bit address bus
 - 32-bit data bus
 - Four levels of hardware-enforced protection
- **Optimized for the cost-sensitive embedded marketplace**
 - Real and protected mode operation without paging
 - Full segmentation unit and descriptor table support
- **Supports world's largest software base for x86 architectures**
- **Compatible with Microsoft at Work[™] and Novell NEST embedded software**
- **Coprocessor interface; supports 387DX-compatible math coprocessor**
- **Advanced packaging options**
 - 132-Pin Plastic Quad Flat Pack
- **Extended temperature versions available**
- **Based on AMD[®] advanced CMOS technology**

AMD ISO48

BLOCK DIAGRAM



18421A-001

FUNCTIONAL DESCRIPTION

True Static Operation

The Am386DE microprocessor incorporates a true static design. Unlike dynamic circuit design, the Am386DE device eliminates the minimum operating frequency restriction. It may be clocked from its maximum speed of 33 MHz all the way down to 0 MHz (DC). System designers can use this feature to design energy-efficient embedded control devices.

Standby Mode

This true static design allows for a standby mode. At any of its operating speeds (33 MHz to 0 MHz), the Am386DE microprocessor will retain its state (i.e., the contents of all of its registers). By shutting off the clock completely, the device enters standby mode. Since power consumption is a function of clock frequency, operating power consumption is reduced as the frequency is lowered. In standby mode, typical current draw is reduced to less than 20 μ A at DC.

Not only does this feature save battery life, but it also simplifies designs in the following ways:

1. Eliminates the need for software in BIOS to save and restore the contents of registers.
2. Allows simpler circuitry to control stopping of the clock since the system does not need to know the processor state.

Lower Operating I_{CC}

True static design also allows lower operating I_{CC} when operating at any speed.

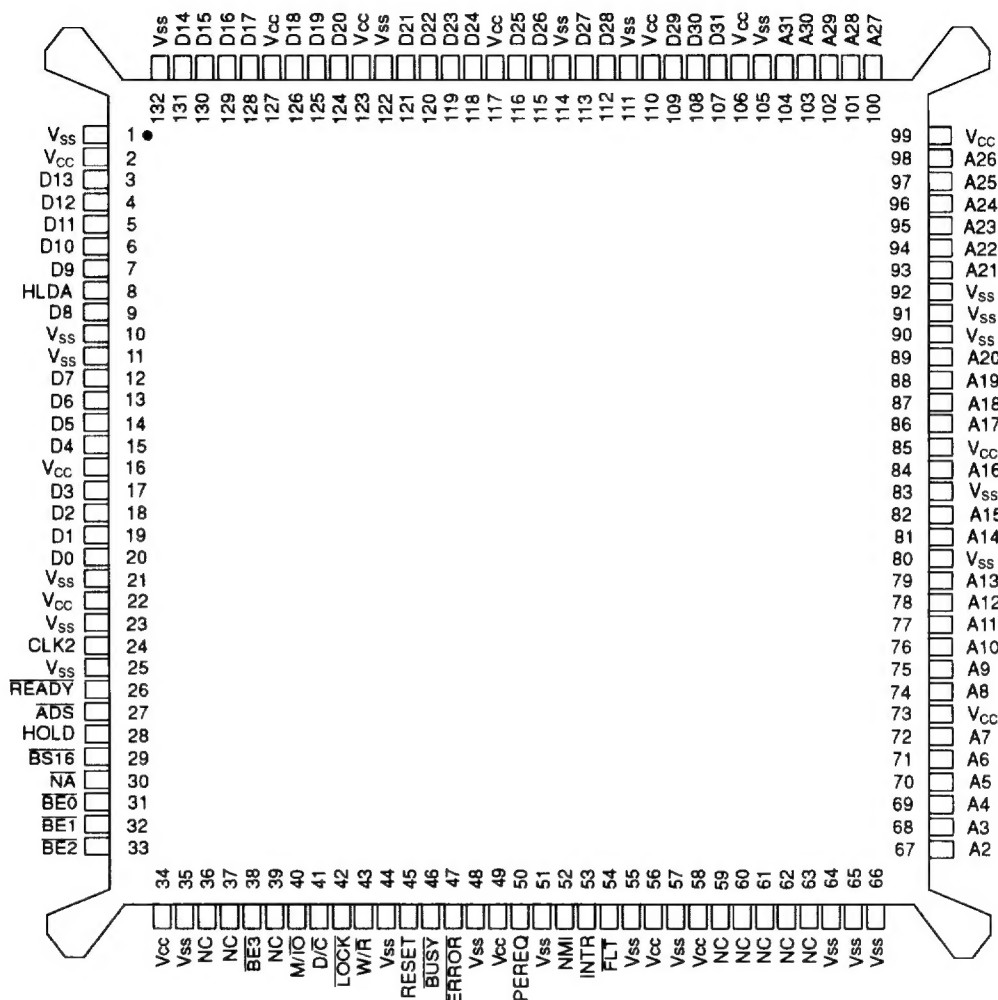
Performance On Demand

The Am386DE microprocessor retains its state at any speed from 0 MHz (DC) to its maximum operating speed of 33 MHz. With this feature, system designers may vary the operating speed of the system to extend the battery life in portable systems, and reduce power and cooling requirements for embedded products.

For example, the system could operate at low speeds during inactivity or polling operations. However, upon interrupt, the system clock can be increased up to its maximum speed. After a user-defined time-out period, the system can be returned to a low (or 0 MHz) operating speed without losing its state. This design maximizes life while achieving optimal performance.

CONNECTION DIAGRAMS

132-Lead Plastic Quad Flat Pack (PQFP) Package—Top Side View



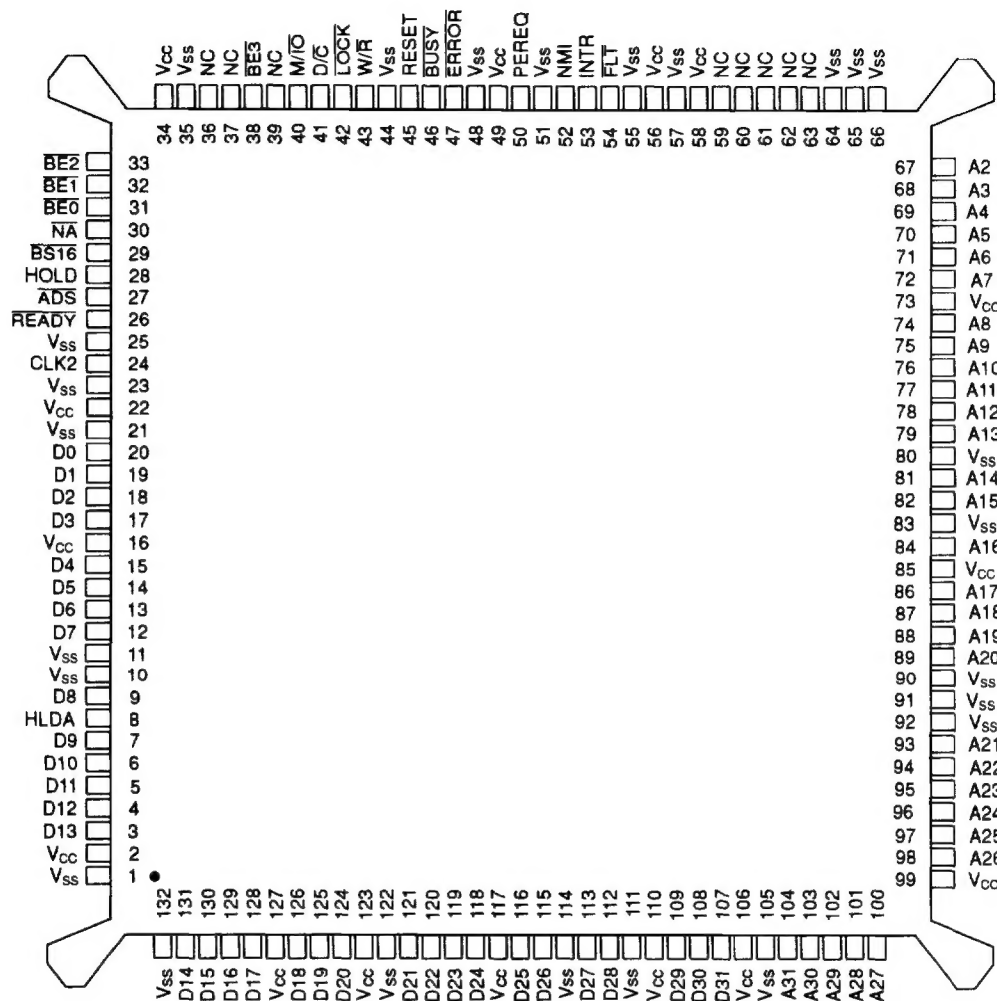
Notes:

Pin 1 is marked for orientation.

NC = Not connected; Connection of an NC pin may cause a malfunction or incompatibility with future versions of the Am386DE microprocessor.

CONNECTION DIAGRAMS (continued)

132-Lead Plastic Quad Flat Pack (PQFP)—Pin Side View

**Notes:**

Pin 1 is marked for orientation.

NC = Not connected; connection of an NC pin may cause a malfunction or incompatibility with future versions of the Am386DE microprocessor.

CONNECTION DIAGRAMS (continued)
PQFP Pin Designations (sorted by Functional Grouping)

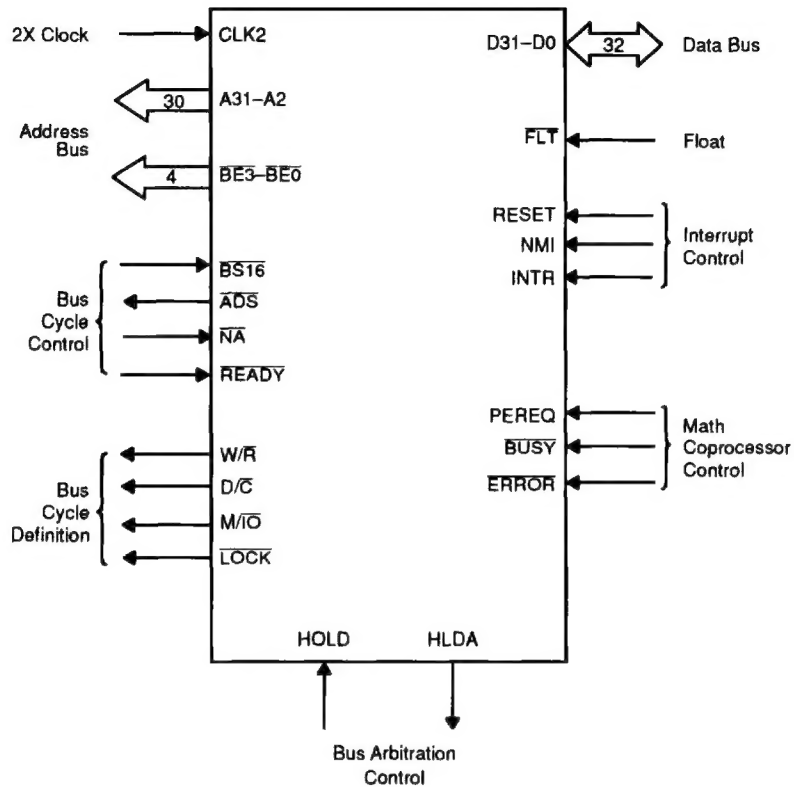
Address		Data		Control		NC	V _{CC}	V _{SS}
Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin No.	Pin No.	Pin No.
A2	67	D0	20	ADS	27	36	2	1
A3	68	D1	19	BE ₀	31	37	16	10
A4	69	D2	18	BE ₁	32	39	22	11
A5	70	D3	17	BE ₂	33	59	34	21
A6	71	D4	15	BE ₃	38	60	49	23
A7	72	D5	14	BS ₁₆	29	61	56	25
A8	74	D6	13	BUSY	46	62	58	35
A9	75	D7	12	CLK2	24	63	73	44
A10	76	D8	9	D/ _C	41		85	48
A11	77	D9	7	ERROR	47		99	51
A12	78	D10	6	FLT	54		106	55
A13	79	D11	5	HLDA	8		110	57
A14	81	D12	4	HOLD	28		117	64
A15	82	D13	3	INTR	53		123	65
A16	84	D14	131	LOCK	42		127	66
A17	86	D15	130	M/ _I O	40			80
A18	87	D16	129	NA	30			83
A19	88	D17	128	NMI	52			90
A20	89	D18	126	PEREQ	50			91
A21	93	D19	125	READY	26			92
A22	94	D20	124	RESET	45			105
A23	95	D21	121	W/ _R	43			111
A24	96	D22	120					114
A25	97	D23	119					122
A26	98	D24	118					132
A27	100	D25	116					
A28	101	D26	115					
A29	102	D27	113					
A30	103	D28	112					
A31	104	D29	109					
		D30	108					
		D31	107					

CONNECTION DIAGRAMS (continued)

PQFP Pin Designations (sorted by Pin Number)

Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name
1	V _{SS}	23	V _{SS}	45	RESET	67	A2	89	A20	111	V _{SS}
2	V _{CC}	24	CLK2	46	BUSY	68	A3	90	V _{SS}	112	D28
3	D13	25	V _{SS}	47	ERROR	69	A4	91	V _{SS}	113	D27
4	D12	26	READY	48	V _{SS}	70	A5	92	V _{SS}	114	V _{SS}
5	D11	27	ADS	49	V _{CC}	71	A6	93	A21	115	D26
6	D10	28	HOLD	50	PEREQ	72	A7	94	A22	116	D25
7	D9	29	BS16	51	V _{SS}	73	V _{CC}	95	A23	117	V _{CC}
8	HLDA	30	NA	52	NMI	74	A8	96	A24	118	D24
9	D8	31	BE0	53	INTR	75	A9	97	A25	119	D23
10	V _{SS}	32	BE1	54	FLT	76	A10	98	A26	120	D22
11	V _{SS}	33	BE2	55	V _{SS}	77	A11	99	V _{CC}	121	D21
12	D7	34	V _{CC}	56	V _{CC}	78	A12	100	A27	122	V _{SS}
13	D6	35	V _{SS}	57	V _{SS}	79	A13	101	A28	123	V _{CC}
14	D5	36	NC	58	V _{CC}	80	V _{SS}	102	A29	124	D20
15	D4	37	NC	59	NC	81	A14	103	A30	125	D19
16	V _{CC}	38	BE3	60	NC	82	A15	104	A31	126	D18
17	D3	39	NC	61	NC	83	V _{SS}	105	V _{SS}	127	V _{CC}
18	D2	40	M/IO	62	NC	84	A16	106	V _{CC}	128	D17
19	D1	41	D/C	63	NC	85	V _{CC}	107	D31	129	D16
20	D0	42	LOCK	64	V _{SS}	86	A17	108	D30	130	D15
21	V _{SS}	43	W/R	65	V _{SS}	87	A18	109	D29	131	D14
22	V _{CC}	44	V _{SS}	66	V _{SS}	88	A19	110	V _{CC}	132	V _{SS}

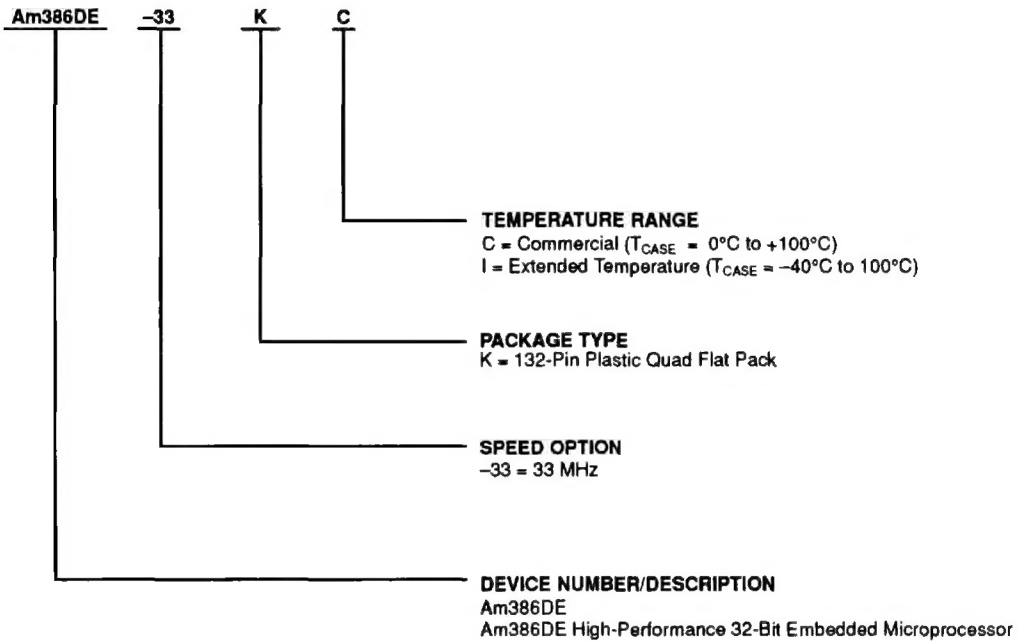
LOGIC SYMBOL



18421A-002

ORDERING INFORMATION**Standard Products**

AMD standard products are available in several packages and operating ranges. The order number (Valid Combination) is formed by a combination of the elements below.



Valid Combinations	
Am386DE	-33KC
Am386DE	-33KI

Valid Combinations

Valid Combinations lists configurations planned to be supported in volume for this device. All speeds may not be available in all package combinations. Consult the local AMD sales office to confirm availability of specific valid combinations and to check on newly released combinations.

PIN DESCRIPTION

A31–A2

Address Bus (Outputs)

Outputs physical memory or port I/O addresses.

ADS

Address Status (Active Low; Output)

Indicates that a valid bus cycle definition and address ($\overline{W/R}$, D/\overline{C} , M/\overline{IO} , $\overline{BE0}$, $\overline{BE1}$, $\overline{BE2}$, $\overline{BE3}$, and A31–A2) are being driven at the Am386DE microprocessor pins.

BE3–BE0

Byte Enables (Active Low; Outputs)

Indicate which data bytes of the data bus take part in a bus cycle.

BS16

Bus Size 16 (Active Low; Input)

Allows direct connection of 32-bit and 16-bit data buses.

BUSY

Busy (Active Low; Input)

Signals a busy condition from a processor extension.

CLK2

Clock (Input)

Provides the fundamental timing for the Am386DE microprocessor.

D31–D0

Data Bus (Inputs/Outputs)

Inputs data during memory, I/O, and interrupt acknowledge read cycles and outputs data during memory and I/O write cycles.

D/C

Data/Control (Output)

A bus cycle definition pin that distinguishes data cycles, either memory or I/O, from control cycles which are: interrupt acknowledge, halt, and instruction fetching.

ERROR

Error (Active Low; Input)

Signals an error condition from a processor extension.

FLT

Float (Active Low; Input)

An input signal which forces all bidirectional and output signals, including HLDA, to the three-state condition.

\overline{FLT} has an internal pull-up resistor, and if it is not used it should be unconnected.

HLDA

Bus Hold Acknowledge (Active High; Output)

Indicates that the Am386DE microprocessor has surrendered control of its local bus to another bus master.

HOLD

Bus Hold Request (Active High; Input)

Allows another bus master to request control of the local bus.

INTR

Interrupt Request (Active High; Input)

A maskable input that signals the Am386DE microprocessor to suspend execution of the current program and execute an interrupt acknowledge function.

LOCK

Bus Lock (Active Low; Output)

A bus cycle definition pin that indicates that other system bus masters are denied access to the system bus while it is active.

M/IO

Memory I/O (Output)

A bus cycle definition pin that distinguishes memory cycles from input/output cycles.

NA

Next Address (Active Low; Input)

Used to request address pipelining.

NC

No Connect

Should always remain unconnected. Connection of an NC pin may cause the processor to malfunction or be incompatible with future steppings of the Am386DE microprocessor.

NMI

Non-Maskable Interrupt Request (Active High; Input)

A non-maskable input that signals the Am386DE microprocessor to suspend execution of the current program and execute an interrupt acknowledge function.

PEREQ

Processor Extension Request (Active High; Input)

Indicates that the processor extension has data to be transferred by the Am386DE microprocessor.

READY

Bus Ready (Active Low; Input)

Terminates the bus cycle.

RESET**Reset (Active High; Input)**

Suspends any operation in progress and places the Am386DE microprocessor in a known reset state.

V_{cc}**System Power (Input)**

Provides 3–5-V nominal DC supply input.

V_{ss}**System Ground (Input)**

Provides 0-V connection from which all inputs and outputs are measured.

W/ \overline{R} **Write/Read (Output)**

A bus cycle definition pin that distinguishes write cycles from read cycles.

BASE ARCHITECTURE

Introduction

The Am386DE microprocessor consists of a central processing unit, a memory management unit, and a bus interface.

The central processing unit consists of the execution unit and instruction unit. The execution unit contains the eight 32-bit general purpose registers that are used for both address calculation, data operations, and a 64-bit barrel shifter used to speed shift, rotate, multiply, and divide operations. The multiply and divide logic uses a 1-bit per cycle algorithm. The multiply algorithm stops the iteration when the most significant bits of the multiplier are all zero. This allows typical 32-bit multiplies to be executed in under 1 ms. The instruction unit decodes the instruction op-codes and stores them in the decoded instruction queue for immediate use by the execution unit.

Memory is organized into one or more variable length segments, each up to 4 Gbytes in size. A given region of the physical address space, a segment, can have attributes associated with it. These attributes include its location, size, type (i.e., stack, code, or data), and protection characteristics. The Am386DE microprocessor can have a maximum of 16,381 segments of up to 4 Gbytes each.

The segmentation unit provides four levels of protection for isolating and protecting applications and the operating system from each other. The hardware enforced protection allows the design of system with a high degree of integrity.

The Am386DE microprocessor has two modes of operation: Real Address Mode (Real Mode) and Protected Address Mode (Protected Mode). In Real Mode, the Am386DE device operates as a very fast 8086 but with 32-bit extensions, if desired. Real Mode is required primarily to setup the processor for Protected Mode operation. Protected Mode provides an address to the sophisticated memory management and privilege capabilities of the processor.

Finally, to facilitate high-performance system hardware designs, the Am386DE microprocessor bus interface offers address pipelining, dynamic data bus sizing, and direct Byte Enable signals for each byte of the data bus. These hardware features are described fully beginning in the Functional Data section.

Register Overview

The Am386DE microprocessor has 28 register resources in the following categories.

- General Purpose Registers
- Segment Registers
- Instruction Pointer and Flags
- Control Register

- System Address Registers
- Debug Registers

The registers are a superset of the 8086, 80186, and 80286 registers, so all 16-bit 80186 and 80286 registers are contained within the 32-bit Am386DE microprocessor.

Figure 1 shows all the Am386DE microprocessor base architecture registers that include the general address and data registers, the instruction pointer, and the flags register. The contents of these registers are task-specific, so these registers are automatically loaded with a new context upon a task switch operation.

The base architecture also includes six directly accessible segments, each up to 4 Gbytes in size. The segments are indicated by the selector values placed in Am386DE CPU segment registers of Figure 1. Various selector values can be loaded as a program executes, if desired.

The selectors are also task specific, so the segment registers are automatically loaded with new context upon a task switch operation.

The other types of registers Control, System Address, and Debug are primarily used by system software.

General Data and Address Registers

31	16	15	0	
			AX	EAX
			BX	EBX
			CX	ECX
			DX	EDX
			SI	ESI
			DI	EDI
			BP	EBP
			SP	ESP

Segment Selector Registers

15	0	
		CS Code
		SS Stack
		DS
		ES Data
		FS
		GS

Instruction Pointer and Flags Registers

31	16	15	0	
			IP	EIP
			FLAGS	EFLAGS

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Figure 1. Base Architecture Registers

Register Descriptions

General-Purpose Registers

The eight general-purpose registers of 32 bits hold data or address quantities. The general registers, Figure 2, support data operands of 1, 8, 16, 32, and 64 bits and bit fields of 1 to 32 bits. They support address operands of 16 and 32 bits. The 32-bit registers are named EAX, EBX, ECX, EDX, ESI, EDI, EBP, and ESP.

The least significant 16 bits of the registers can be accessed separately. This is done by using the 16-bit names of the registers AX, BX, CX, DX, SI, DI, BP, and SP. When accessed as a 16-bit operand, the upper 16 bits of the register are neither used nor changed.

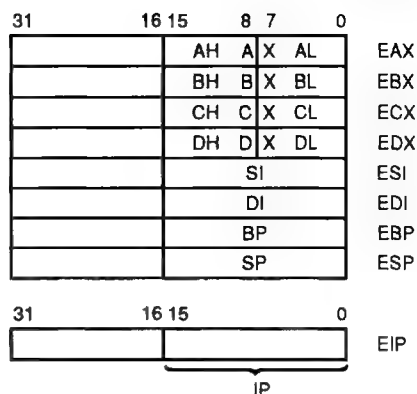
Finally, 8-bit operations can individually access the lower byte (bits 7–0) and the higher byte (bits 15–8) of general purpose registers AX, BX, CX, and DX. The lower bytes are named AL, BL, CL, and DL, respectively. The higher bytes are named AH, BH, CH, and DH, respectively. The individual byte accessibility offers additional flexibility for data operations, but is not used for effective address calculation.

Instruction Pointer

The instruction pointer, Figure 2, is a 32-bit register named EIP. EIP holds the offset of the next instruction to be executed. The offset is always relative to the base of the code segment (CS). The lower 16 bits (bits 15–0) of EIP contain the 16-bit instruction pointer named IP, which is used by 16-bit addressing.

Flags Register

The Flags Register is a 32-bit register named EFLAGS. The defined bits and bit fields within EFLAGS, shown in Figure 3, control certain operations and indicate status



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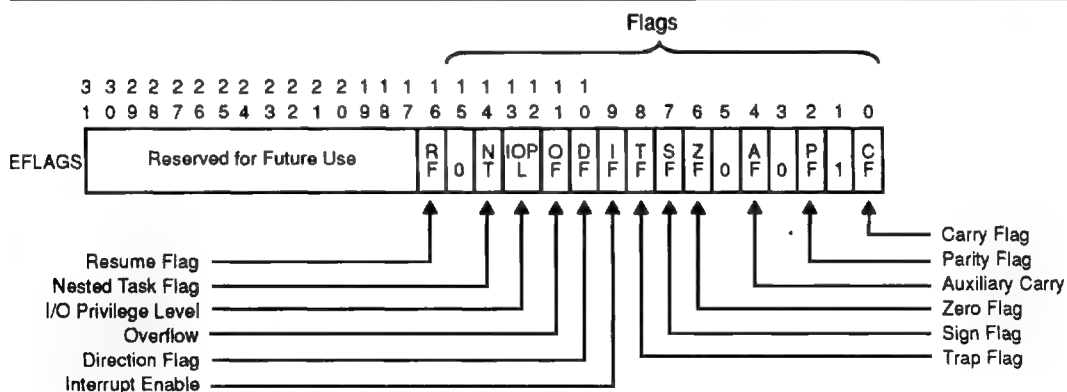
Figure 2. General Registers and Instruction Pointer

of the Am386DE microprocessor. The lower 16 bits (bits 15–0) of EFLAGS contain the 16-bit flag register named FLAGS, which is most useful when executing 8086 and 80286 code.

Note in the following descriptions, *set* means set to 1 and *reset* means reset to 0.

RF (Resume Flag, bit 16)

The RF flag is used in conjunction with the debug register breakpoints. It is checked at instruction boundaries before breakpoint processing. When RF is set, it causes any debug fault to be ignored on the next instruction. RF is then automatically reset at the successful completion of every instruction (no faults are signaled) except the



Note:

0 indicates "Reserved for Future Use." Do not define; see the Compatibility section on page 17.

Figure 3. Flags Registers

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IRET instruction and the POPF instruction. (JMP, CALL, and INT instructions causing a task switch.) These instructions set RF to the value specified by the memory image. For example, at the end of the breakpoint service routine, the IRET instruction can pop an EFLAGS image having the RF bit set and resume the program's execution at the breakpoint address without generating another breakpoint fault on the same location.

NT (Nested Task, bit 14)

This flag applies to Protected Mode. NT is set to indicate that the execution of this task is nested within another task. If set, it indicates that the current nested task's Task State Segment (TSS) has a valid back link to the previous task's TSS. This bit is set or reset by control transfers to other tasks. The value of NT in EFLAGS is tested by the IRET instruction to determine whether to do an inter-task return or an intra-task return. A POPF or an IRET instruction will affect the setting of this bit according to the image popped at any privilege level.

IOPL (Input/Output Privilege Level, bits 12–13)

This two-bit field applies to Protected Mode. IOPL indicates the numerically maximum CPL (current privilege level) value permitted to execute I/O instructions without generating an Exception 13 fault or consulting the I/O Permission Bitmap. It also indicates the maximum CPL value allowing alteration of the IF (INTR Enable Flag) bit when new values are popped into the EFLAGS register. POPF and IRET instruction can alter the IOPL field when executed at CPL = 0. Task switches can always alter the IOPL field when the new flag image is loaded from the incoming task's TSS.

OF (Overflow Flag, bit 11)

OF is set if the operation resulted in a signed overflow. Signed overflow occurs when the operation resulted in carry/borrow into the sign bit (high-order bit) of the result but did not result in a carry/borrow out of the high-order bit or vice-versa. For 8-, 16-, and 32-bit operations, OF is set according to overflow at bits 7, 15, and 31, respectively.

DF (Direction Flag, bit 10)

DF defines whether ESI and/or EDI registers post-decrement or postincrement during the sg instructions. Postincrement occurs if DF is reset. Postdecrement occurs if DF is set.

IF (INTR Enable Flag, bit 9)

The IF flag, when set, allows recognition of external interrupts signaled on the INTR pin. When IF is reset, external interrupts signaled on the INTR are not recognized. IOPL indicates the maximum CPL

value allowing alteration of the IF bit when new values are popped into EFLAGS or FLAGS.

TF (Trap Enable Flag, bit 8)

TF controls the generation of Exception 1 trap when single-stepping through code. When TF is set, the Am386DE microprocessor generates an Exception 1 trap after the next instruction is executed. When TF is reset, Exception 1 traps occur only as a function of the breakpoint addresses loaded into debug register DR3–DR0.

SF (Sign Flag, bit 7)

SF is set if the high-order bit of the result is set; it is reset otherwise. For 8-, 16-, and 32-bit operations, SF reflects the state of bits 7, 15, and 31, respectively.

ZF (Zero Flag, bit 6)

ZF is set if all bits of the result are 0. Otherwise it is reset.

AF (Auxiliary Carry Flag, bit 4)

The Auxiliary Flag is used to simplify the addition and subtraction of packed BCD quantities. AF is set if the operation resulted in a carry out of bit 3 (addition) or a borrow into bit 3 (subtraction). Otherwise, AF is reset. AF is affected by carry out of, or borrow into, bit 3 only; regardless of overall operand length: 8, 16, or 32 bits.

PF (Parity flags, bit 2)

PF is set if the low-order 8 bits of the operation contain an even number of 1s (even parity). PF is reset if the low-order 8 bits have odd parity. PF is a function of only the low-order 8 bits, regardless of operand size.

CF (Carry Flag, bit 0)

CF is set if the operation resulted in a carry out of (addition) or a borrow into (subtraction) the high-order bit. Otherwise, CF is reset. For 8-, 16-, or 32-bit operations, CF is set according to carry/borrow at bits 7, 15, or 31, respectively.

Segment Registers

Six 16-bit segment registers hold segment selector values identifying the currently addressable memory segments. Segment registers are shown in Figure 4. In Protected Mode, each segment may range in size from one byte up to the entire linear and physical space of the machine, 4 Gb (2^{32} bytes). If a maximum sized segment is used (limit = FFFFFFFFH), it should be Dword aligned (i.e., the least two significant bits of the segment base should be zero). This alignment will avoid a segment limit violation (Exception 13) caused by the wrap around. In Real Address Mode, the maximum segment size is fixed at 64 Kb (2^{16} bytes).

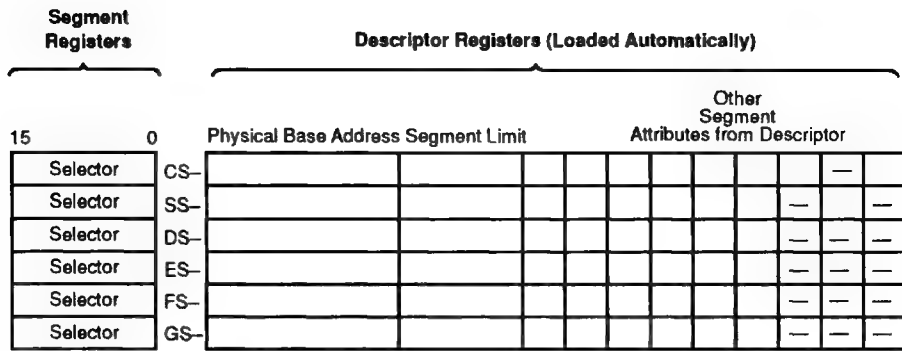


Figure 4. Segment Registers and Associated Descriptor Registers

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The six segments addressable at any given moment are defined by the segment registers: CS, SS, DS, ES, FS, and GS. The selector in SS indicates the current stack segment; the selectors in DS, ES, FS, and GS indicate the current data segments.

Segment Descriptor Registers

The segment descriptor registers are not programmer visible, yet it is very useful to understand their content. Inside the Am386DE microprocessor, a descriptor register (programmer invisible) is associated with each programmer-visible segment register, as shown by Figure 4. Each descriptor register holds a 32-bit segment base address, a 32-bit segment limit, and the other necessary segment attributes.

When a selector value is loaded into a segment register, the associated descriptor register is automatically updated with the correct information. In Real Address Mode, only the base address is updated directly (by shifting the selector value four bits to the left), since the segment maximum limit and attributes are fixed in Real Mode. In Protected Mode, the base address, the limit, and the attributes are all updated per the contents of the segment descriptor indexed by the selector.

Whenever a memory reference occurs, the segment descriptor register associated with the segment being used is automatically involved with the memory reference. The 32-bit segment base address becomes a component of the physical address calculation, the 32-bit limit is used for the limit-check operation, and the attributes are checked against the type of memory reference requested.

Control Register

The Am386DE microprocessor has a 32-bit control register, CR0, to hold the machine state of a global nature. This register, along with System Address Registers described in the next section, hold machine state that

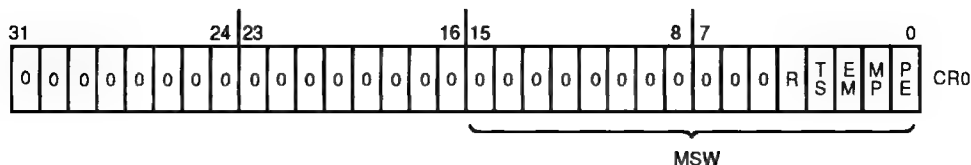
affects all tasks in the system. To access the Control Registers, load and store instructions are defined.

CR0: Machine Control Register (Includes 80286 Machine Status Word)

CR0, shown in Figure 5, contains six defined bits for control and status purposes. The low-order 16 bits of CR0 are also known as the Machine Status Word (MSW) for compatibility with 80286 Protected Mode. LMSW and SMSW instructions are taken as special aliases of the load and store CR0 operations, where only the low-order 16 bits of CR0 are involved. For compatibility with 80286 operating systems, the Am386DE microprocessor LMSW instructions work in an identical fashion to the LMSW instruction on the 80286 (i.e., it only operates on the low-order 16 bits of CR0 and it ignores the new bits in CR0). New Am386DE microprocessor operating systems should use the MOV CR0, Reg instruction.

The defined CR0 bits are described below.

- R** (Reserved, bit 4)
This bit is Reserved for Future Use. When loading CR0 care should be taken to not alter the value of this bit.
- TS** (Task Switched, bit 3)
TS is automatically set whenever a task switch operation is performed. If TS is set, a coprocessor ESCape op-code will cause a Coprocessor Not Available trap (Exception 7). The trap handler typically saves a 387DX math coprocessor context belonging to a previous task, loads a 387DX math coprocessor state belonging to the current task, and clears the TS bit before returning to the faulting coprocessor op-code.
- EM** (Emulate Coprocessor, bit 2)
The Emulate coprocessor bit is set to cause all coprocessor op-codes to generate a Coprocessor



Note:

0 indicates "Reserved for Future Use." Do not define; see the Compatibility section on page 17.

Figure 5. Control Register 0

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Not Available fault (Exception 7). It is reset to allow coprocessor op-codes to be executed on an actual 387DX math coprocessor (this is the default case after reset). Note that the WAIT op-code is not affected by the EM bit setting.

MP (Monitor Coprocessor, bit 1)

The MP bit is used in conjunction with the TS bit to determine if the WAIT op-code will generate a Coprocessor Not Available fault (Exception 7) when TS = 1. When both MP = 1 and TS = 1, the WAIT op-code generates a trap. Otherwise, the WAIT op-code does not generate a trap. Note that TS is automatically set whenever a task switch operation is performed.

PE (Protection Enable, bit 0)

The PE bit is set to enable the Protected Mode. If PE is reset, the processor operates again in Real Mode. PE may be set by loading MSW or CR0. PE can be reset only by a load into CR0. Resetting the PE bit is typically part of a longer instruction sequence needed for proper transition from Protected Mode to Real Mode. Note that for strict 80286 compatibility, PE cannot be reset by the LMSW instruction.

CR1: Reserved

CR1 is reserved for future processors.

System Address Registers

Four special registers are defined to reference the tables or segments supported by the 80286 CPU and Am386DE microprocessor protection model.

These tables or segments are:

- GDT (Global Descriptor Table)
- IDT (Interrupt Descriptor Table)
- LDT (Local Descriptor Table)
- TSS (Task State Segment)

The addresses of these tables and segments are stored in special registers, the System Address and System Segment Registers illustrated in Figure 6. These registers are named GDTR, IDTR, LDTR, and TR, respectively. The Protected Mode Architecture section describes the use of these registers.

GDTR and IDTR

These registers hold the 32-bit linear base address and 16-bit limit of the GDT and IDT, respectively.

The GDT and IDT segments, since they are global to all tasks in the system, are defined by 32-bit linear addresses and 16-bit limit values.

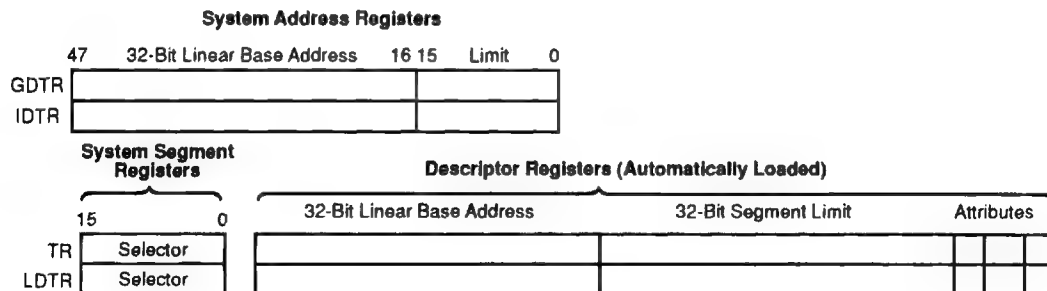


Figure 6. System Address and System Segment Registers

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LDTR and TR

These registers hold the 16-bit selector for the LDT descriptor and the TSS descriptor, respectively.

The LDT and TSS segments, since they are task-specific segments, are defined by selector values stored in the system segment registers. Note that a segment descriptor register (programmer-invisible) is associated with each system segment register.

Debug Registers

Debug Registers: The six programmer accessible debug registers provide on-chip support for debugging. Debug Registers DR3–DR0 specify the four linear breakpoints. The Debug Control Register DR7 is used to set the breakpoints, and the Debug Status Register DR6 displays the current state of the breakpoints. The use of the debug registers is described in the Debugging Support section. Figure 7 shows the Debug registers.

Register Accessibility

There are a few differences regarding the accessibility of the registers in Real and Protected Mode. Table 1

summarizes these differences. See the Protected Mode Architecture section for further details.

Compatibility With Future Processors

In the preceding register descriptions, note certain Am386DE microprocessor register bits are Reserved for Future Use. When reserved bits are called out, treat them as fully undefined. This is essential for software compatibility with future processors! Follow the guidelines below:

1. Do not depend on the state of any undefined bits when testing the values of defined register bits. Mask them out when testing.
2. Do not depend on the state of any undefined bits when storing them to memory or another register.
3. Do not depend on the ability to retain information written into any undefined bits.
4. When loading registers, always load the undefined bits as zeros.
5. However, registers that have been previously stored may be reloaded without masking.

Depending upon the values of undefined register bits will make your software dependent upon the unspecified Am386DE microprocessor handling of these bits. Depending on undefined values risks making software incompatible with future processors that define usages for the Am386DE CPU undefined bits. Avoid any software dependence upon the state of undefined Am386DE CPU register bits.

Debug Registers	
31	0
Linear Breakpoint Address 0	DR0
Linear Breakpoint Address 1	DR1
Linear Breakpoint Address 2	DR2
Linear Breakpoint Address 3	DR3
Reserved for Future use. Do not define.	DR4
Reserved for Future use. Do not define.	DR5
Breakpoint Status	DR6
Breakpoint Control	DR7

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Figure 7. Debug Registers**Table 1. Register Usage**

Register	Use In Real Mode		Use In Protected Mode	
	Load	Store	Load	Store
General Registers	Yes	Yes	Yes	Yes
Segment Registers	Yes	Yes	Yes	Yes
Flag Registers	Yes	Yes	Yes	Yes
Control Register	Yes	Yes	PL = 0	PL = 0
GDTR	Yes	Yes	PL = 0	Yes
IDTR	Yes	Yes	PL = 0	Yes
LDTR	No	No	PL = 0	Yes
TR	No	No	PL = 0	Yes
Debug Control	Yes	Yes	PL = 0	PL = 0

Note:

PL = 0: The registers can be accessed only when the current privilege level is zero.

Instruction Set

Instruction Set Overview

The instruction set is divided into nine categories of operations.

- Data Transfer
- Arithmetic
- Shift/Rotate
- String Manipulation
- Bit Manipulation
- Control Transfer
- High Level Language Support
- Operating System Support
- Processor Control

These Am386DE microprocessor instructions are listed in Table 2.

All Am386DE microprocessor instructions operate on either 0, 1, 2, or 3 operands where an operand resides in a register in the instruction itself or in memory. Most zero operand instructions (e.g., CLI, STI) take only one byte. One operand instructions generally are two bytes long. The average instruction is 3.2-bytes long. Since the Am386DE device has a 16-byte instruction queue, an average of 5 instructions will be prefetched. The use of two operands permits the following types of common instructions.

- Register to Register
- Memory to Register
- Immediate to Register
- Register to Memory
- Immediate to Memory

The operands can be either 8-, 16-, or 32-bits long. As a general rule, when executing code written for the Am386DE microprocessor (32-bit code), operands are 8 or 32 bits; when executing existing 80286 or 8086 code (16-bit code), operands are 8 or 16 bits. Prefixes can be added to instructions that override the default length of the operands (i.e., use 32-bit operands for 16-bit code or 16-bit operands for 32-bit code).

Addressing Modes

Addressing Modes Overview

The Am386DE microprocessor provides a total of 11 addressing modes for instructions to specify operands. The addressing modes are optimized to allow the efficient execution of high-level languages such as C and FORTRAN, and they cover the vast majority of data references needed by high-level languages.

Register and Immediate Modes

Two of the addressing modes provide for instructions that operate on register or immediate operands:

Register Operand Mode: The operand is located in one of the 8-, 16-, or 32-bit general registers.

Immediate Operand Mode: The operand is included in the instruction as part of the op-code.

32-Bit Memory Addressing Modes

The remaining nine modes provide a mechanism for specifying the effective address of an operand. The physical address consists of two components: the segment base address and an effective address. The effective address is calculated by using combinations of the following four address elements.

Displacement: An 8- or 32-bit immediate value following the instruction.

Base: The contents of any general-purpose register. The Base registers are generally used by compilers to point to the start of the local variable area.

Index: The contents of any general-purpose register except for ESP. The Index registers are used to access the elements of an array, or a string of characters.

Scale: The index register's value can be multiplied by a scale factor of either 1, 2, 4, or 8. Scaled index mode is especially useful for accessing arrays or structures.

Combinations of these four components make up the nine additional addressing modes. There is no performance penalty for using any of these addressing combinations, since the effective address calculation is pipelined with the execution of other instructions.

The one exception is the simultaneous use of Base and Index components that requires one additional clock.

As shown in Figure 8, the effective address (EA) of an operand is calculated according to the following formula:

$$EA = \text{Base Reg} + (\text{Index Reg} \cdot \text{Scaling}) + \text{Displacement}$$

Direct Mode: The operand's offset is contained as part of the instruction as an 8-, 16-, or 32-bit displacement.

Example: INC Word PTR [500]

Register Indirect Mode: A Base register contains the address of the operand.

Example: MOV [ECX], EDX

Based Mode: A Base register's contents is added to a Displacement to form the operands offset.

Example: MOV ECX, [EAX + 24]

Index Mode: An Index register's contents is added to a Displacement to form the operands offset.

Example: ADD EAX, TABLE [ESI]

Scaled Index Mode: An Index register's contents is multiplied by a scaling factor that is added to a Displacement to form the operands offset.

Example: IMUL EBX, TABLE [ESI * 4], 7

Based Index Mode: The contents of a Base register is added to the contents of an Index register to form the effective address of an operand.

Example: MOV EAX, [ESI] [EBX]

Based Scaled Index Mode: The contents of an Index register is multiplied by a Scaling factor and the result is added to the contents of a Base register to obtain the operands offset.

Example: MOV ECX, [EDX * 8] [EAX]

Based Index Mode with Displacement: The contents of an Index Register and a Base register's contents and a Displacement are all summed together to form the operand offset.

Example: ADD EDX, [ESI] [EBP + 00FFFF0H]

Based Scaled Index Mode with Displacement: The contents of an Index register are multiplied by a Scaling factor; the result is added to the contents of a Base register and a Displacement to form the operand's offset.

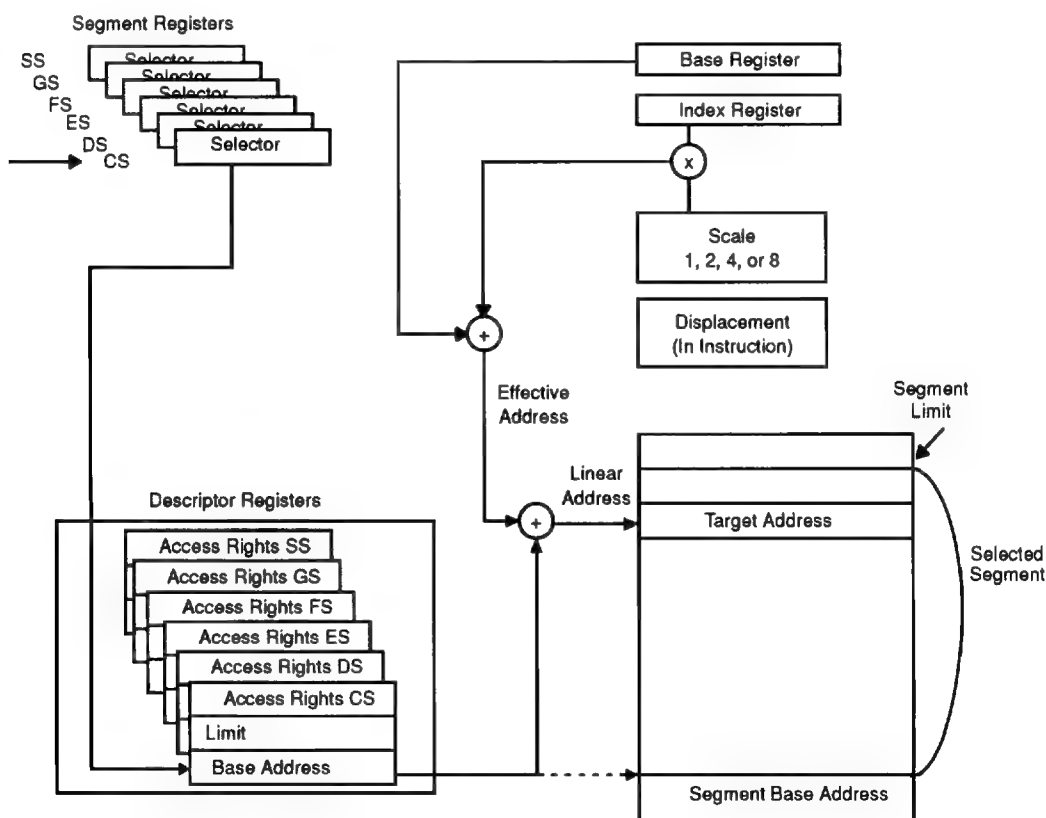
Example: MOV EAX, LOCALTABLE[EDI * 4] [EBP + 80]

Figure 8. Addressing Mode Calculations

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Table 2. Am386DE Microprocessor Instructions

Table 2a. Data Transfer

General Purpose	
MOV	Move operand
PUSH	Push operand onto stack
POP	Pop operand off stack
PUSHA	Push all registers on stack
POPA	Pop all registers off stack
XCHG	Exchange operand register
XLAT	Translate
Conversion	
MOVZX	Move byte or Word, Dword with zero extension
MOVSX	Move byte or Word, Dword, sign extended
CBW	Convert byte to Word, or Word to Dword
CWD	Convert Word to Dword
CWDE	Convert Word to Dword extended
CDQ	Convert Dword to Qword
Input/Output	
IN	Input operand from I/O space
OUT	Output operand to I/O space
Address Object	
LEA	Load effective address
LDS	Load pointer into D segment register
LES	Load pointer into E segment register
LFS	Load pointer into F segment register
LGS	Load pointer into G segment register
LSS	Load pointer into S (Stack) segment register
Flag Manipulation	
LAHF	Load A register from Flags
SAHF	Store A register in Flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack
PUSHFD	Push EFLAGS onto stack
POPFD	Pop EFLAGS off stack
CLC	Clear Carry Flag
CLD	Clear Direction Flag
CMC	Complement Carry Flag
STC	Set Carry Flag
STD	Set Direction Flag

Table 2b. Arithmetic Instructions

Addition	
ADD	Add operands
ADC	Add with carry
INC	Increment operand by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
Subtraction	
SUB	Subtract operands
SBB	Subtract with borrow
DEC	Decrement operand by 1
NEG	Negate operand
CMP	Compare operands
DAS	Decimal adjust for subtraction
AAS	ASCII adjust for subtraction
Multiplication	
MUL	Multiply Double/Single Precision
IMUL	Integer multiply
AAM	ASCII adjust after multiply
Division	
DIV	Divide unsigned
IDIV	Integer divide
AAD	ASCII adjust before division

Table 2c. String Instructions

MOVS	Move byte or Word, Dword string
INS	Input string from I/O space
OUTS	Output string to I/O space
CMPS	Compare byte or Word, Dword string
SCAS	Scan Byte or Word, Dword string
LODS	Load byte or Word, Dword string
STOS	Store byte or Word, Dword string
REP	Repeat
REPE/ REPZ	Repeat while equal/zero
RENE/ REPNZ	Repeat while not equal/not zero

Table 2. Am386DE Microprocessor Instructions (continued)

Table 2d. Logical Instructions

Logicals	
NOT	"NOT" operand
AND	"AND" operands
OR	"Inclusive OR" operands
XOR	"Exclusive OR" operands
TEST	"Test" operands
Shifts	
SHL/SHR	Shift logical left or right
SAL/SAR	Shift arithmetic left or right
SHLD/SHRD	Double shift left or right
Rotates	
ROL/ROR	Rotate left/right
RCL/RCR	Rotate through carry left/right

Table 2e. Bit Manipulation Instructions

Single Bit Instructions	
BT	Bit Test
BTS	Bit Test and Set
BTR	Bit Test and Reset
BTC	Bit Test and Complement
BSF	Bit Scan Forward
BSR	Bit Scan Reverse

Table 2f. Program Control Instructions

Conditional Transfers	
SETCC	Set byte equal to condition code
JA/JNBE	Jump if above/not below nor equal
JAE/JNB	Jump if above or equal/not below
JB/JNAE	Jump if below/not above nor equal
JBE/JNA	Jump if below or equal/not above
JC	Jump if carry
JE/JZ	Jump if equal/zero
JG/JNLE	Jump if greater/not less nor equal
JGE/JNL	Jump if greater or equal/not less
JL/JNGE	Jump if less/not greater nor equal
JLE/JNG	Jump if less or equal/not greater
JNC	Jump if not carry
JNE/JNZ	Jump if not equal/not zero
JNO	Jump if not overflow
JNP/JPO	Jump if not parity/parity odd
JNS	Jump if not sign
JO	Jump if overflow
JP/JPE	Jump if parity/parity even
JS	Jump if sign

Table 2g. Program Control Instructions (continued)

Unconditional Transfers	
CALL	Call procedure/task
RET	Return from procedure
JMP	Jump
Iteration Controls	
LOOP	Loop
LOOPE/LOOPZ	Loop if equal/zero
LOOPNE/LOOPNZ	Loop if not equal/not zero
JCXZ	JUMP if register CX = 0
Interrupts	
INT	Interrupt
INTO	Interrupt if overflow
IRET	Return from interrupt/task
CLI	Clear interrupt enable
STI	Set interrupt enable

Table 2h. High Level Language Instructions

BOUND	Check array bounds
ENTER	Setup parameter block for entering procedure
LEAVE	Leave procedure

Table 2i. Protection Model

SGDT	Store global descriptor table
SIDT	Store interrupt descriptor table
STR	Store task register
SLDT	Store local descriptor table
LGDT	Load global descriptor table
LIDT	Load interrupt descriptor table
LTR	Load task register
LLDT	Load local descriptor table
ARPL	Adjust requested privilege level
LAR	Load access rights
LSL	Load segment limit
VERR/VERW	Verify segment for reading or writing
LMSW	Load machine status word (lower 16 bits of CR0)
SMSW	Store machine status word

Table 2j. Processor Control Instructions

HLT	Halt
WAIT	Wait until BUSY negated
ESC	Escape
LOCK	Lock Bus

Differences Between 16- and 32-Bit Addresses

In order to provide software compatibility with the 80286 and the 8086, the Am386DE microprocessor can execute 16-bit instructions in Real and Protected Modes. The processor determines the size of the instructions it is executing by examining the D bit in the CS segment descriptor. If the D bit is 0 then all operand lengths and effective addresses are assumed to be 16 bits long. If the D bit is 1 then the default length for operands and addresses is 32 bits. In Real Mode, the default size for operands and addresses is 16 bits.

Regardless of the default precision of the operands or addresses, the Am386DE microprocessor is able to execute either 16- or 32-bit instructions. This is specified via the use of override prefixes. Two prefixes, the Operand Size Prefix and the Address Length Prefix, override the value of the D bit on an individual instruction basis.

Example: The processor is executing in Real Mode and the programmer needs to access the EAX registers. The assembler code for this might be MOV EAX, 32-bit MEMORYOP. An assembler automatically determines that an Operand Size Prefix is needed and generates it.

Example: The D bit is 0 and the programmer wishes to use Scaled Index addressing mode to access an array. The Address Length Prefix allows the use of MOV DX, TABLE [ESI • 2]. The assembler uses an Address Length Prefix, since with D = 0, the default addressing mode is 16 bits.

Example: The D bit is 1 and the program wants to store a 16-bit quantity. The Operand Length Prefix is used to specify only a 16-bit value: MOV MEM16, DX.

The Operand Length and Address Length prefixes can be applied separately or in combination to any instruction. The Address Length Prefix does not allow addresses over 64 Kbytes to be accessed in Real Mode. A memory address exceeding FFFFH will result in a General Protection Fault. An Address Length Prefix only allows the use of the additional Am386DE microprocessor addressing modes.

When executing 32-bit code, the Am386DE microprocessor uses either 8- or 32-bit displacements, and any register can be used as base or index registers. When executing 16-bit code, the displacements are either 8 or 16 bits, and the base and index register conform to the 80286 model. Table 3 illustrates the differences.

Data Types

The Am386DE microprocessor supports all data types commonly used in high-level languages.

Bit: A single bit quantity.

Bit Field: A group of up to 32 contiguous bits that spans a maximum of four bytes.

Bit String: A set of contiguous bits on the Am386DE microprocessor bit strings can be up to 4 Gbytes long.

Byte: A signed 8-bit quantity.

Unsigned Byte: An unsigned 8-bit quantity.

Integer (Word): A signed 16-bit quantity.

Long Integer (Double Word): A signed 32-bit quantity. All operations assume a 2's complement representation.

Unsigned Integer (Word): An unsigned 16-bit quantity.

Unsigned Long Integer (Double Word): An unsigned 32-bit quantity.

Signed Quad Word: A signed 64-bit quantity.

Unsigned Quad Word: An unsigned 64-bit quantity.

Offset: A 16- or 32-bit offset only quantity that indirectly references another memory location.

Pointer: A full pointer which consists of a 16-bit segment selector and either a 16- or 32-bit offset.

Char: A byte representation of an ASCII alphanumeric or control character.

String: A contiguous sequence of bytes, words, or Dwords. A string may contain between 1 byte and 4 Gbytes.

BCD: A byte (unpacked) representation of decimal digits 0–9.

Packed BCD: A byte (packed) representation of two decimal digits 0–9 storing one digit in each nibble.

When the Am386DE microprocessor is coupled with a 387DX math coprocessor then the following common floating-point types are supported.

Table 3. Base and Index Registers for 16- and 32-Bit Addresses

	16-Bit Addressing	32-Bit Addressing
Base Register	BX, BP	Any 32-bit GP Register
Index Register	SI, DI	Any 32-bit GP Register Except ESP
Scale Factor	None	1, 2, 4, 8
Displacement	0, 8, 16 bits	0, 8, 32 bits

Floating Point: A signed 32-, 64-, or 80-bit real number representation. Floating-point numbers are supported by a 387DX compatible math coprocessor.

Figure 9 illustrates the data types supported by the Am386DE microprocessor and a 387DX compatible math coprocessor.

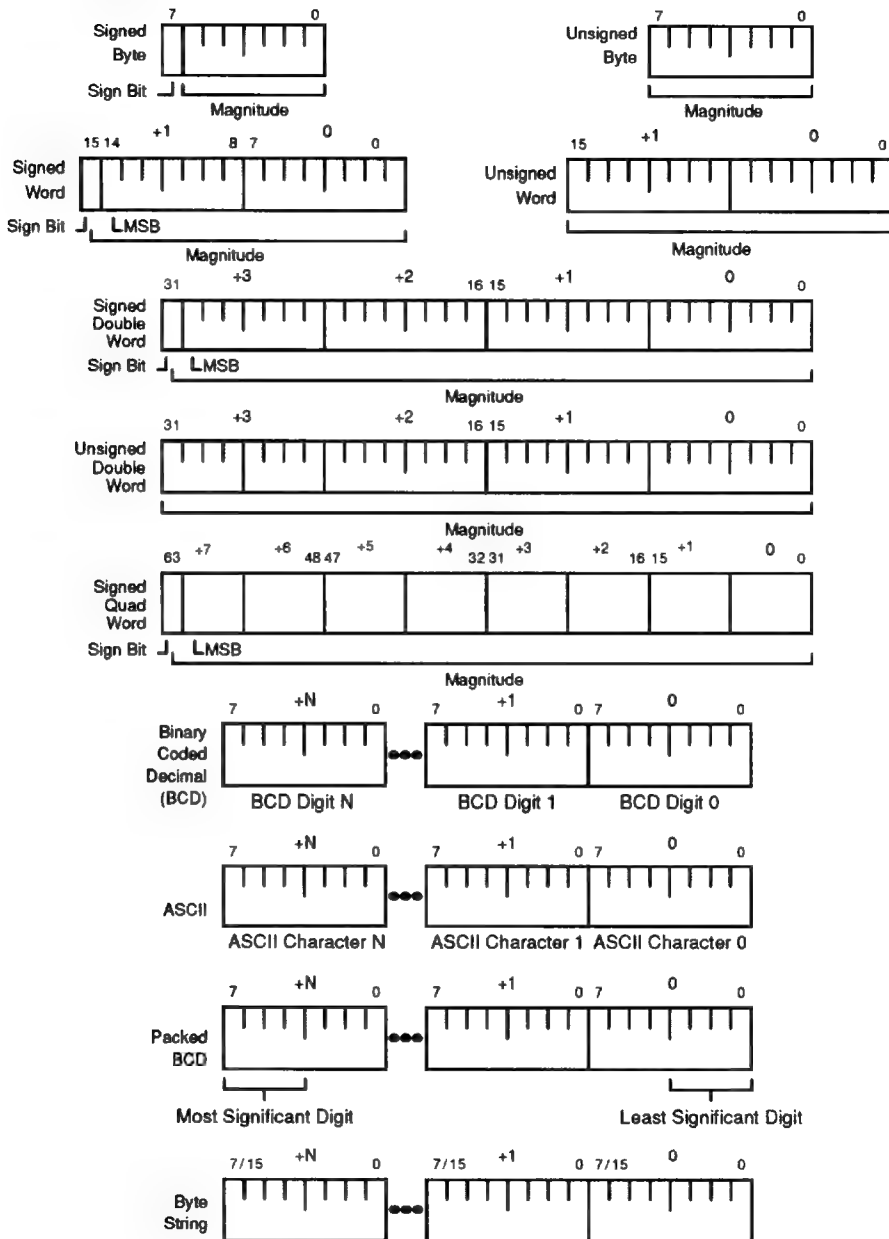
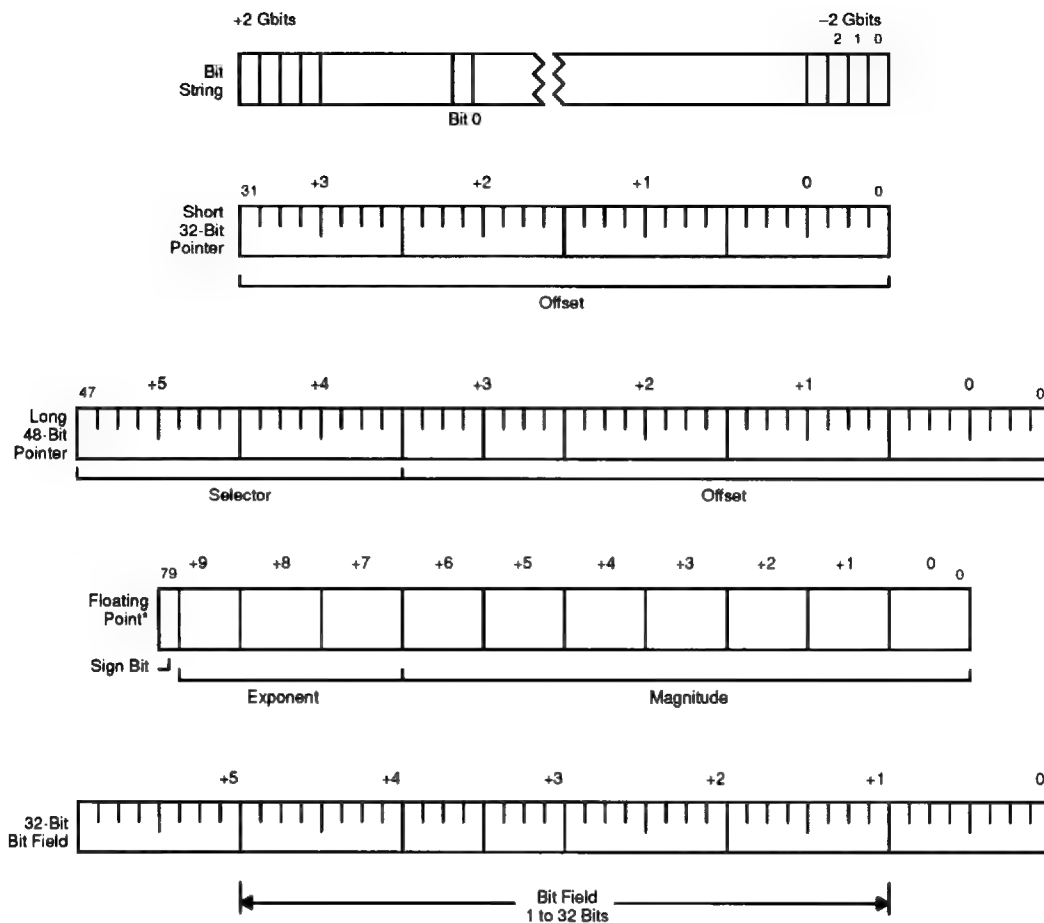


Figure 9. Supported Data Types

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Note:

* Supported by 387DX-compatible math coprocessor.

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Figure 9. Supported Data Types (continued)

Memory Organization

Introduction

Memory on the Am386DE microprocessor is divided up into 8-bit quantities (Bytes), 16-bit quantities (Words), and 32-bit quantities (Dwords). Words are stored in two consecutive bytes in memory with the low-order byte at the lowest address, the high-order byte at the highest address. Dwords are stored in four consecutive bytes in memory with the low-order byte at the lowest address, the high-order byte at the highest address. The address of a word or Dword is the byte address of the low-order byte.

In addition to these basic data types, the Am386DE microprocessor supports larger variable length units with segmentation. Memory can be divided up into one or more variable length segments, which can be shared between programs. Segmentation is useful for organizing memory in logical modules, and as such is a tool for the application programmer.

Address Spaces

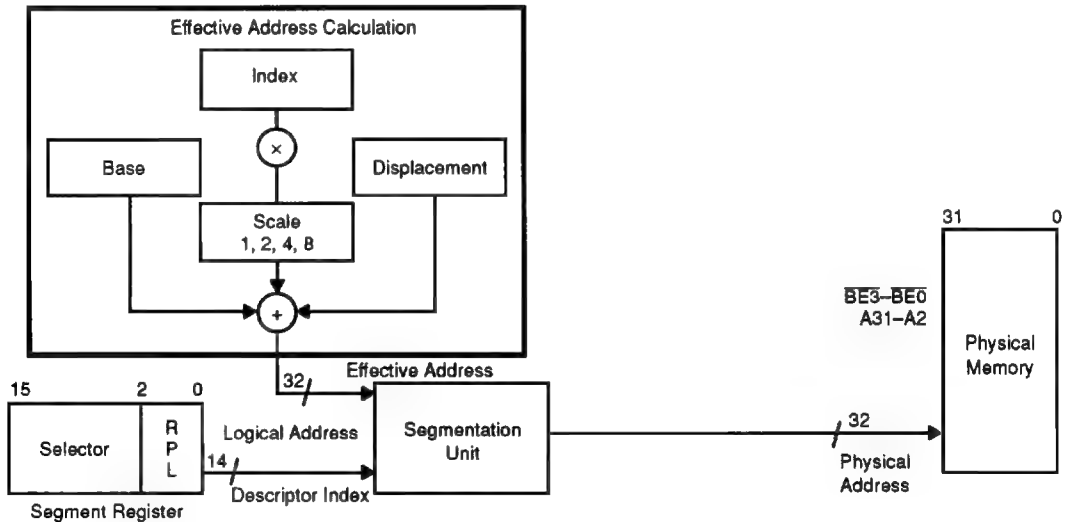
The Am386DE microprocessor has two distinct address spaces: logical and physical. A logical address (also known as a virtual address) consists of a selector and an

offset. A selector is the contents of a segment register. An offset is formed by summing all of the addressing components (Base, Index, Displacement) discussed in Section Memory Address Modes into an effective address. Each task on Am386DE CPU has a maximum of 16K ($2^{14} - 1$) selectors.

The segmentation unit translates the logical address space into a 32-bit physical address space. The physical address is what appears on the address pins. The total address space of the Am386DE is 4 Gbytes.

The primary difference between Real Mode and Protected Mode is how the segmentation unit performs the translation of the logical address into the physical address. In Real Mode, the segmentation unit shifts the selector left four bits and adds the result to the offset to form the physical address. While in Protected Mode, every selector has a base address associated with it. The base address is stored in one of two operating system tables (i.e., the Local Descriptor Table or Global Descriptor Table). The selector's linear base address is added to the offset to form the final physical address.

Figure 10 shows the relationship between the address spaces.



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Figure 10. Address Translation

Segment Register Usage

The main data structure used to organize memory is the segment. On the Am386DE microprocessor, segments are variable sized blocks of physical addresses that have certain attributes associated with them. There are two main types of segments: code and data. The segments are of variable size and can be as small as 1 byte or as large as 4 Gbytes (2^{32} bytes).

In order to provide compact instruction encoding and increase processor performance, instructions do not need to explicitly specify which segment register is used. A default segment register is automatically chosen according to the rules of Table 4 (Segment Register Selection Rules). In general, data references use the selector contained in the DS register; Stack references use the SS register; and Instruction fetches use the CS register. The contents of the Instruction Pointer provides the offset. Special segment override prefixes allow the explicit use of a given segment register, and override the implicit rules listed in Table 4. The override prefixes also allow the use of the ES, FS, and GS segment registers.

There are no restrictions regarding the overlapping of the base addresses of any segments. Thus, all 6 segments could have the base address set to zero and create a system with a 4-Gb physical address space. This creates a system where the virtual address space is the same as the physical address space. Further details of segmentation are discussed in the Protected Mode Architecture section on page 36.

I/O Space

The Am386DE microprocessor has two distinct physical address spaces: Memory and I/O. Generally, peripherals are placed in I/O space although the Am386DE CPU also supports memory-mapped peripherals. The I/O space consists of 64 Kbytes and can be divided into 64K 8-bit ports, 32K 16-bit ports, or 16K 32-bit ports, or any combination of ports that add up to less than 64 Kbytes. The 64-Kbyte I/O address space refers to physical memory since I/O instructions do not go through the segmentation hardware. The M/I \bar{O} pin acts as an additional address line, thus allowing the system designer to easily determine which address space the processor is accessing.

The I/O ports are accessed via the IN and OUT I/O instructions, with the port address supplied as an immediate 8-bit constant in the instruction or in the DX register. All 8- and 16-bit port addresses are zero extended on the upper address lines. The I/O instructions cause the M/I \bar{O} pin to be driven Low.

I/O port addresses 00F8H through 00FFH are reserved.

Interrupts

Interrupts and Exceptions

Interrupts and exceptions alter the normal program flow, in order to handle external events, to report errors or exceptional conditions. The difference between interrupts and exceptions is that interrupts are used to

Table 4. Segment Register Selection Rules

Type of Memory Reference	Implied (Default) Segment Use	Segment Override Prefixes Possible
Code Fetch	CS	None
Destination of PUSH, PUSHF, INT, CALL, PUSHA Instructions	SS	None
Source of POP, POPA, POPF, IRET, RET Instructions	SS	None
Destination of STOS, MOVS, REP STOS, REP MOVS Instructions (DI is Base Register)	ES	None
Other Data References with Effective Address Using Base Register of:		
[EAX]	DS	CS, SS, ES, FS, GS
[EBX]	DS	CS, SS, ES, FS, GS
[ECX]	DS	CS, SS, ES, FS, GS
[EDX]	DS	CS, SS, ES, FS, GS
[ESI]	DS	CS, SS, ES, FS, GS
[EDI]	DS	CS, SS, ES, FS, GS
[EBP]	SS	CS, SS, ES, FS, GS
[ESP]	SS	CS, SS, ES, FS, GS

handle asynchronous external events while exceptions handle instruction faults. Although a program can generate a software interrupt via an INT n instruction, the processor treats software interrupts as exceptions.

Hardware interrupts occur as the result of an external event and are classified into two types: maskable or non-maskable. Interrupts are serviced after the execution of the current instruction. After the interrupt handler is finished servicing the interrupt, execution proceeds with the instruction immediately after the interrupted instruction. The differences between the interrupts are discussed in the Maskable Interrupt and Non-Maskable Interrupt sections.

Exceptions are classified as faults, traps, or aborts depending on the way they are reported, and whether or not restart of the instruction causing the exception is supported. Faults are exceptions that are detected and serviced before the execution of the faulting instruction. A fault occurs in a virtual memory system when the processor references a segment that is not present. The operating system fetches the segment, and then the Am386DE microprocessor restarts the instruction. Traps are exceptions that are reported immediately after the execution of the instruction that caused the problem. User defined interrupts are examples of traps. Aborts

are exceptions that do not permit the precise location of the instruction causing the exception to be determined. Aborts are used to report severe errors, such as a hardware error or illegal values in system tables.

Thus, when an interrupt service routine has been completed, execution proceeds from the instruction immediately following the interrupted instruction. On the other hand, the return address from an exception fault routine will always point at the instruction causing the exception and include any leading instruction prefixes. Table 5 summarizes the possible interrupts for the Am386DE microprocessor and shows where the return address points.

The Am386DE microprocessor has the ability to handle up to 256 different interrupts/exceptions. In order to service the interrupts, a table with up to 256 interrupt vectors must be defined. The interrupt vectors are simply pointers to the appropriate interrupt service routine. In Real Mode (see the Real Mode Introduction section on page 34), the vectors are 4 byte quantities, a Code Segment plus a 16-bit offset; in Protected Mode, the interrupt vectors are 8 byte quantities that are put in an Interrupt Descriptor Table (see the Introduction section on page 36). Of the 256 possible interrupts, 32 are Reserved for Future Use, the remaining 224 are free to be used by the system designer.

Table 5. Interrupt Vector Assignments

Function	Interrupt Number	Instructions Which Can Cause Exceptions	Return Address Points to Faulting Instruction	Type
Divide Error	0	DIV, IDIV	Yes	FAULT
Debug Exception	1	Any instruction	Yes	TRAP*
NMI Interrupt	2	INT 2 or NMI	No	NMI
One Byte Interrupt	3	INT	No	TRAP
Interrupt on Overflow	4	INTO	No	TRAP
Array Bounds Check	5	BOUND	Yes	FAULT
Invalid Op-Code	6	Any illegal instruction	Yes	FAULT
Device Not Available	7	ESC, WAIT	Yes	FAULT
Double Fault	8	Any instruction that can generate an Exception		ABORT
Coprocessor Segment Overrun	9	ESC	No	ABORT
Invalid TSS	10	JMP, CALL, IRET, INT	Yes	FAULT
Segment Not Present	11	Segment register instructions	Yes	FAULT
Stack Fault	12	Stack references	Yes	FAULT
General Protection Fault	13	Any memory reference	Yes	FAULT
Reserved for Future Use	14			
Reserved for Future Use	15			
Coprocessor Error	16	ESC, WAIT	Yes	FAULT
Reserved for Future Use	17–31			
Two Byte Interrupt	0–255	INT n	No	TRAP

Note:

*Some debug exceptions may report both traps on the previous instruction and faults on the next instruction.

Interrupt Processing

When an interrupt occurs the following actions happen.

- First, the current program address and the Flags are saved on the stack to allow resumption of the interrupted program.
- Next, an 8-bit vector is supplied to the Am386DE microprocessor that identifies the appropriate entry in the interrupt table. The table contains the starting address of the interrupt service routine. Then, the user supplied interrupt service routine is executed.
- Finally, when an IRET instruction is executed the old processor state is restored and program execution resumes at the appropriate instruction.

The 8-bit interrupt vector is supplied to the Am386DE microprocessor in several different ways: exceptions supply the interrupt vector internally; software INT instructions contain or imply the vector; maskable hardware interrupts supply the 8-bit vector via the interrupt acknowledge bus sequence. Non-Maskable hardware interrupts are assigned to interrupt vector 2.

Maskable Interrupt

Maskable interrupts are the most common way the Am386DE microprocessor responds to asynchronous external hardware events. A hardware interrupt occurs when the INTR is pulled High and the Interrupt Flag bit (IF) is enabled. The processor only responds to interrupts between instructions (REPEAT string instructions have an interrupt window between memory moves, which allows interrupts during long string moves). When an interrupt occurs, the processor reads an 8-bit vector supplied by the hardware that identifies the source of the interrupt (one of 224 user defined interrupts). The exact nature of the interrupt sequence is discussed in the Functional Data section on page 52.

The IF bit in the EFLAGS register is reset when an interrupt is being serviced. This effectively disables servicing additional interrupts during an interrupt service routine. However, the IF bit may be set explicitly by the interrupt handler to allow the nesting of interrupts. When an IRET instruction is executed, the original state of the IF bit is restored.

Non-Maskable Interrupt

Non-maskable interrupts provide a method of servicing very high priority interrupts. A common example of the use of a non-maskable interrupt (NMI) would be to activate a power failure routine. When the NMI input is pulled High it causes an interrupt with an internally supplied vector value of 2. Unlike a normal hardware interrupt, no interrupt acknowledgment sequence is performed for NMI.

While executing the NMI servicing procedure, the Am386DE microprocessor will not service further NMI requests until an interrupt return (IRET) instruction is executed or the processor is reset. If NMI occurs while

currently servicing an NMI, its presence will be saved for servicing after executing the first IRET instruction. The IF bit is cleared at the beginning of an NMI interrupt to inhibit further INTR interrupts.

Software Interrupts

A third type of interrupt/exception for the Am386DE microprocessor is the software interrupt. An INT n instruction causes the processor to execute the interrupt service routine pointed to by the nth vector in the interrupt table.

A special case of the two byte software interrupt INT n is the one byte INT 3 or breakpoint interrupt. By inserting this one byte instruction in a program, the user can set breakpoints in the program as a debugging tool.

A final type of software interrupt is the single step interrupt. It is discussed in the Debugging Support section on page 30.

Interrupt and Exception Priorities

Interrupts are externally-generated events. Maskable Interrupts (on the INTR input) and Non-Maskable Interrupts (on the NMI input) are recognized at instruction boundaries. When NMI and maskable INTR are both recognized at the same instruction boundary, the Am386DE microprocessor invokes the NMI service routine first. If after the NMI service routine has been invoked, maskable interrupts are still enabled, then the Am386DE CPU invokes the appropriate interrupt service routine.

Table 6. Am386DE Microprocessor Priority for Invoking Service Routines in Case of Simultaneous External Interrupts

1. NMI
2. INTR

Exceptions are internally-generated events. Exceptions are detected by the Am386DE microprocessor if in the course of executing an instruction, the Am386DE CPU detects a problematic condition. The Am386DE microprocessor then immediately invokes the appropriate exception service routine. The state of the Am386DE CPU is such that the instruction causing the exception can be restarted. If the exception service routine has taken care of the problematic condition, the instruction will execute without causing the same exception.

It is possible for a single instruction to generate several exceptions. However, only one exception is generated upon each attempt to execute the instruction. Each exception service routine should correct its corresponding exception, and restart the instruction. In this manner, exceptions are serviced until the instruction executes successfully.

As the Am386DE microprocessor executes instructions, it follows a consistent cycle in checking for exceptions. This cycle is detailed in the sequence of Exception Checking and is repeated as each instruction is executed and occurs in parallel with instruction decoding and execution.

Exception Checking Sequence

Instruction Restart

The Am386DE microprocessor fully supports restarting all instructions after faults. If an exception is detected in the instruction to be executed (Exception Categories 4 through 9 in the Sequence of Exception Checking), the Am386DE device invokes the appropriate exception service routine.

Consider the case of the Am386DE microprocessor having just completed an instruction. It then performs the following checks before reaching the point where the next instruction is completed:

1. Check for Exception 1 Traps from the instruction just completed (single-step via Trap Flag or Data Breakpoints set in the Debug Registers).
2. Check for Exception 1 Faults in the next instruction (Instruction Execution Breakpoint set in the Debug Registers for the next instruction).
3. Check for external NMI and INTR.
4. Check for Segmentation Faults that prevented fetching the entire next instruction (Exceptions 11 and 13).
5. Check for Faults decoding the next instruction [Exception 6 if illegal op-code; Exception 6 if in Real Mode and attempting to execute an instruction for Protected Mode only (see the Protection section on page 45 and the I/O Permission Bitmap section on page 46); or Exception 13 if instruction is longer than 15 bytes, or privilege violation in Protected Mode (i.e., not at IOPL or at CPL = 0)].
6. If WAIT op-code, check if TS = 1 and MP = 1 (Exception 7 if both are 1).
7. If ESCAPE op-code for numeric coprocessor, check if EM = 1 or TS = 1 (Exception 7 if either are 1).
8. If WAIT op-code or ESCAPE op-code for numeric coprocessor, check ERROR input signal (Exception 16 if ERROR input is asserted).
9. Check each memory reference required by the instruction for Segmentation Faults that prevent transferring the entire memory quantity (Exceptions 11, 12, 13).

Double Fault

A Double Fault (Exception 8) results when the processor attempts to invoke an exception service routine for the segment exceptions (10, 11, 12, or 13), but in the process of doing so, detects an exception.

When a Double Fault occurs, the Am386DE microprocessor invokes the exception service routine for Exception 8.

Reset and Initialization

When the processor is initialized or Reset, the registers have the values shown in Table 7. The Am386DE microprocessor will then start executing instructions near the top of physical memory, at location FFFFFFF0H. When the first Inter-Segment Jump or Call is executed, address lines A31–A20 will drop Low for CS-relative memory cycles, and the Am386DE microprocessor will only execute instructions in the lower 1 Mb of physical memory. This allows the system designer to use a ROM at the top of physical memory to initialize the system and take care of Resets.

RESET forces the Am386DE microprocessor to terminate all execution and local bus activity. No instruction execution or bus activity will occur as long as Reset is active. Between 350 and 450 CLK2 periods after Reset becomes inactive, the Am386DE device will start executing instructions at the top of physical memory.

Table 7. Register Values after Reset

Flag Word	UUUU0002H	Note 1
Machine Status Word (CR0)	UUUUUUU0H	Note 2
Instruction Pointer	0000FFF0H	
Code Segment	F000H	Note 3
Data Segment	0000H	
Stack Segment	0000H	
Extra Segment (ES)	0000H	
Extra Segment (FS)	0000H	
Extra Segment (GS)	0000H	
DX Register	Component and Stepping ID	Note 5
All Other Registers	Undefined	Note 4

Notes:

1. EFLAGS Register. The upper 14 bits of the EFLAGS register are undefined, RF (Bit 16) and 0 (Bit 15) are all other defined flag bits.
2. CR0: (Machine Status Word). All of the defined fields in the CR0 are 0 (TS Bit 3, EM Bit 2, MP Bit 1, and PE Bit 0).
3. The code Segment Register (CS) will have its Base Address set to FFFF0000H and Limit set to 0FFFFH.
4. All undefined bits are Reserved for Future Use and should not be used.
5. DX register always holds component and stepping identifier (see Section Component and Revision Identifiers). EAX register holds self-test signature if self-test was requested (see the Self-Test Signature section on page 88).

Testability

Self-Test

The Am386DE microprocessor has the capability to perform a self-test. The self-test checks the function of all the Control ROM and most of the non-random logic of the part. Approximately one-half of the Am386DE microprocessor can be tested during self-test.

Self-Test is initiated on the Am386DE microprocessor when the RESET pin transitions from High to Low, and the $\overline{\text{BUSY}}$ pin is Low. The self-test takes about 2^{19} clocks or approximately 26 ms with a 20-MHz Am386DE device. At the completion of self-test, the processor performs reset and begins normal operation. The part has successfully passed self-test if the contents of the EAX register are zero (0). If the results of EAX are not zero, then the self-test has detected a flaw in the part.

Debugging Support

The Am386DE microprocessor provides several features that simplify the debugging process.

The three categories of on-chip debugging aids are:

1. The code execution breakpoint op-code (0CCH);
2. The single-step capability provided by the TF bit in the flag register; and,
3. The code and data breakpoint capability provided by the Debug Registers DR3–DR0, DR6, and DR7.

Breakpoint Instruction

A single-byte op-code breakpoint instruction is available for use by software debuggers. The breakpoint op-code is 0CCh and generates an Exception 3 trap when executed. In typical use, a debugger program can plant the breakpoint instruction at all desired code execution breakpoints. The single-byte breakpoint op-code is an alias for the two-byte general software interrupt instruction, INT n, where $n = 3$. The only difference between INT 3 (0CCh) and INT n is that INT 3 is never IOPL-sensitive; but, INT n is IOPL-sensitive in Protected Mode.

LENI (Breakpoint Length Specification Bits)

A 2-bit LEN field exists for each of the four breakpoints. LEN specifies the length of the associated breakpoint field. The choices for data breakpoints are: 1 byte, 2 bytes, and 4 bytes. Instruction execution breakpoints must have a length of 1 (LEN_i = 00; see Table 8).

Table 8. LENI Field Encoding

LENI Encoding	Breakpoint Field Width	Use of Least Significant Bits in Breakpoint Address Register I, (i = 0 – 3)
00	1 byte	All 32 bits used to specify a single-byte breakpoint field.
01	2 bytes	A31–A1 used to specify a two-byte, word-aligned breakpoint field. A0 in Breakpoint Address Register is not used.
10	Undefined—do not use this encoding	
11	4 bytes	A31–A2 used to specify a four-byte, Dword-aligned breakpoint field. A0 and A1 in Breakpoint Address Register are not used.

The LEN_i field controls the size of breakpoint field *i* by controlling whether all low-order physical address bits in the breakpoint address register are used to detect the breakpoint event. Therefore, all breakpoint fields are aligned; 2-byte breakpoint fields begin on Word boundaries and 4-byte breakpoint fields begin on Dword boundaries.

Figure 12 shows various size breakpoint fields. Assume the breakpoint physical address in DR2 is 00000005H. In that situation, the following illustration indicates the region of the breakpoint field for lengths of 1, 2, or 4 bytes.

RWI (Memory Access Qualifier Bits)

A 2-bit RW field exists for each of the four breakpoints. The 2-bit RW field specifies the type of usage that must occur in order to activate the associated breakpoint (see Table 9).

RW encoding 00 is used to set up an instruction execution breakpoint. RW encodings 01 or 11 are used to set up write-only or read/write data breakpoints.

Note that instruction execution breakpoints are taken as faults (i.e., before the instruction executes), but data breakpoints are taken as traps (i.e., after the data transfer takes place).

Table 9. Associated Breakpoint Encoding

RW Encoding	Usage Causing Breakpoint
00	Instruction execution only
01	Data writes only
10	Undefined—do not use this encoding
11	Data reads and writes only

Using LENi and RWI to Set Data Breakpoint i

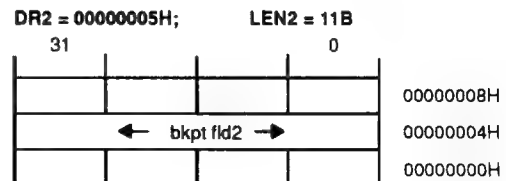
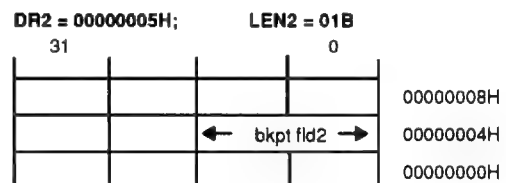
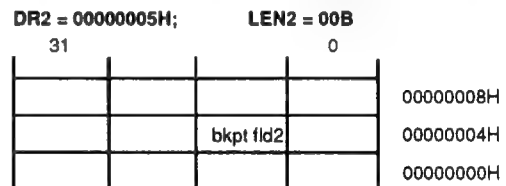
A data breakpoint can be set up by writing the physical address into DRI ($i = 0-3$). For data breakpoints, RWi can = 01 (write only) or 11 (write/read). LEN can = 00, 01, or 11.

If a data access falls entirely or partly within the data breakpoint field, the data breakpoint condition has occurred, and if the breakpoint is enabled, an Exception 1 trap will occur.

Using LENI and RWI to Set Instruction Execution Breakpoint i

An instruction execution breakpoint can be set up by writing address of the beginning of the instruction (including prefixes if any) into DRi (i = 0-3). RWi must = 00 and LEN must = 00 for instruction execution breakpoints.

Figure 12. Breakpoint Fields



If the instruction beginning at the breakpoint address is about to be executed, the instruction execution breakpoint condition has occurred, and if the breakpoint is enabled, an Exception 1 fault will occur before the instruction is executed.

Note that an instruction execution breakpoint address must be equal to the beginning byte address of an instruction (including prefixes) in order for the instruction execution breakpoint to occur.

GD (Global Debug Register Access Detect)

The Debug Registers can only be accessed in Real Mode or at privilege level 0 in Protected Mode. The GD bit, when set, provides extra protection against any Debug Register access even in Real Mode or at privilege level 0 in Protected Mode. This additional protection feature is provided to guarantee that a software debugger or emulator can have full control over the Debug Register resources when required. The GD bit, when set, causes an Exception 1 fault if an instruction attempts to read or write any Debug Register. The GD bit is then automatically cleared when the Exception 1 handler is invoked, allowing the Exception 1 handler free access to the debug registers.

GE and LE (Exact Data Breakpoint Match, Global and Local)

If either GE or LE is set, any data breakpoint trap will be reported exactly after completion of the instruction that caused the operand transfer. Exact reporting is provided by forcing the Am386DE microprocessor execution unit to wait for completion of data operand transfers before beginning execution of the next instruction.

If exact data breakpoint match is not selected, data breakpoints may not be reported until several instructions later or may not be reported at all. When enabling a data breakpoint, it is therefore recommended to enable the exact data breakpoint match.

When the Am386DE microprocessor performs a task switch, the LE bit is cleared. Thus, the LE bit supports fast task switching out of tasks that have enabled the exact data breakpoint match for their task-local breakpoints. The LE bit is cleared by the processor during a task switch to avoid having exact data breakpoint match enabled in the new task. Note that exact data breakpoint match must be re-enabled under software control.

The Am386DE microprocessor GE bit is unaffected during a task switch. The GE bit supports exact data breakpoint match that is to remain enabled during all tasks executing in the system.

Note that instruction execution breakpoints are always reported exactly, whether or not exact data breakpoint match is selected.

GI and LI (Breakpoint Enable, Global and Local)

If either Gi or Li is set, then the associated breakpoint (as defined by the physical address in DRI, the length in LENi and the usage criteria in RWi) is enabled. If either Gi or Li is set and the Am386DE microprocessor detects the breakpoint condition, then the Exception 1 handler is invoked.

When the Am386DE microprocessor performs a task switch to a new Task State Segment (TSS), all Li bits are cleared. Thus, the Li bits support fast task switching out of tasks that use some task-local breakpoint registers. The Li bits are cleared by the processor during a task switch to avoid spurious exceptions in the new task. Note that the breakpoints must be enabled under software control.

All Am386DE microprocessor Gi bits are unaffected during a task switch. The Gi bits support breakpoints that are active in all tasks executing in the system.

Debug Status Register (DR6)

A Debug Status Register, DR6, shown in Figure 11, allows the Exception 1 handler to easily determine why it was invoked. Note the Exception 1 handler can be invoked as a result of one of several events.

1. DR0 Breakpoint fault/trap.
2. DR1 Breakpoint fault/trap.
3. DR2 Breakpoint fault/trap.
4. DR3 Breakpoint fault/trap.
5. Single-step (TF) trap.
6. Task switch trap.
7. Fault due to attempted debug register access when GD = 1.

The Debug Status Register contains single-bit flags for each of the possible events invoking Exception 1. Note below that some of these events are faults (exception taken before the instruction is executed), while other events are traps (exception taken after the debug events occurred).

The flags in DR6 are set by the hardware but never cleared by hardware. Exception 1 handler software should clear DR6 before returning to the user program to avoid future confusion in identifying the source of Exception 1.

The fields within the Debug Status Register DR6 are as follows.

BI (Debug Fault/Trap Due to Breakpoint 0-3)

Four breakpoint indicator flags, B3-B0, correspond one-to-one with the breakpoint registers in DR3-DR0. A flag Bi is set when the condition described by DRI, LENi, and RWi occurs.

If Gi or Li is set, and if the breakpoint is detected, the processor will invoke the Exception 1 handler. The exception is handled as a fault if an instruction execution breakpoint occurred or as a trap if a data breakpoint occurred.

Important Note: A flag, Bi, is set whenever the hardware detects a match condition on enabled breakpoint i. Whenever a match is detected on at least one enabled breakpoint i, the hardware immediately sets all Bi bits corresponding to breakpoint conditions matching at that instant, whether enabled or not. Therefore, the Exception 1 handler may see that multiple Bi bits are set, but only set Bi bits corresponding to enabled breakpoints (Li or Gi set) are true indications of why the Exception 1 handler was invoked.

BD (Debug Fault Due to Attempted Register Access When GD Bit Set)

This bit is set if the Exception 1 handler was invoked due to an instruction attempting to read or write to the debug registers when GD bit was set. If such an event occurs, then the GD bit is automatically cleared when the Exception 1 handler is invoked, allowing handler access to the debug registers.

BS (Debug Trap Due to Single-Step)

This bit is set if the Exception 1 handler was invoked due to the TF bit in the flag register being set (for single-stepping). See the Single-Step Trap section on page 31.

BT (Debug Trap Due to Task Switch)

This bit is set if the Exception 1 handler was invoked due to a task switch occurring to a task having an Am386DE microprocessor TSS with the T-bit set. (See Figure 26 on page 47) Note the task switch into the new task occurs normally, but before the first instruction of the task is executed, the Exception 1 handler is invoked. With respect to the task switch operation, the operation is considered to be a trap.

Use of Resume Flag (RF) In Flag Register

The Resume Flag (RF) in the flag word can suppress an instruction execution breakpoint when the Exception 1 handler returns to a user program at a user address that is also an instruction execution breakpoint. See the Flags Register section on page 13.

REAL MODE ARCHITECTURE

Real Mode Introduction

When the processor is reset or powered up, it is initialized in Real Mode. Real Mode has the same base architecture as the 8086, but allows access to the 32-bit register set of the Am386DE microprocessor. The addressing mechanism, memory size, and interrupt handling are all identical to the Real Mode on the 80286.

Most Am386DE microprocessor instructions are available in Real Mode (except those instructions listed in the Protection section on page 45 and the I/O Permission Bitmap section on page 46). The default operand size in Real Mode is 16 bits, just like the 8086. In order to use the 32-bit registers and addressing modes, override prefixes must be used. In addition, the segment size on the Am386DE CPU in Real Mode is 64 Kbytes so 32-bit effective addresses must have a value less than 0000FFFFH. The primary purpose of Real Mode is to set up the processor for Protected Mode Operation.

Several instructions, particularly those applying to the multitasking model and protection model, are available only in Protected Mode. Therefore, attempting to

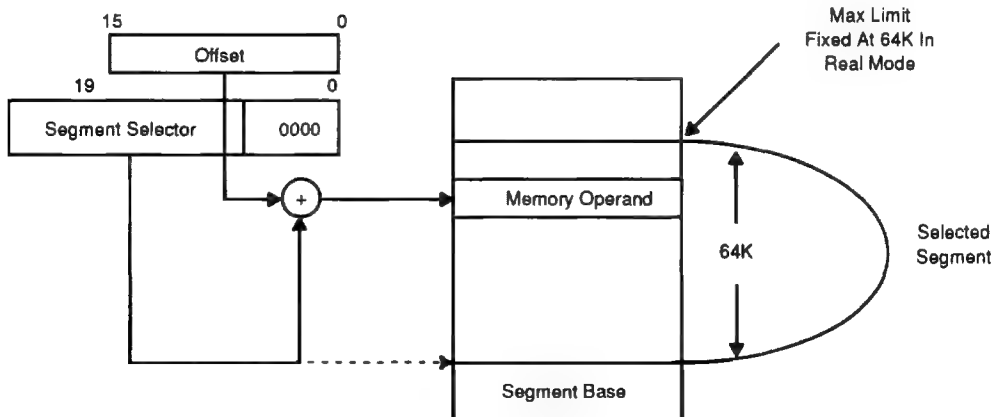


Figure 13. Real Address Mode Addressing

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execute the following instructions in Real Mode generates an Exception 6 fault.

LTR; STR;
 LLDT; SLDT;
 LAR; VERR;
 LSL; VERW;
 ARPL.

LOCK Operation

Table 10 shows the only instruction forms where the LOCK prefix is legal on the Am386DE microprocessor.

Table 10. Legal Lock Prefix Instruction Forms

Opcode	Operands (Dest, Source)
BIT TEST and SET/RESET/COMPLEMENT	Mem, Reg/immed
XCHG	Reg, Mem
XCHG	Mem, Reg
ADD, OR, ADC, SBB, AND, SUB, XOR	Mem, Reg/immed
NOT, NEG, INC, DEC	Mem

An Exception 6 will be generated if a LOCK prefix is placed before any instruction form or op-code not listed above. The LOCK prefix allows indivisible read/modify/write operations on memory operands using the instructions above. For example, even the ADD Reg, Mem is not LOCKable, because the Mem operand is not the destination (and therefore no memory read/modify/operation is being performed).

Since, on the Am386DE microprocessor, repeated string instructions are not LOCKable, it is not possible to LOCK the bus for a long period of time. Therefore, the LOCK prefix is not IOPL-sensitive on the Am386DE device. The LOCK prefix can be used at any privilege level, but only on the instruction forms listed above.

Memory Addressing

In Real Mode, the maximum memory size is limited to 1 Mbyte. Thus, only address lines A19–A2 are active.

One exception is that the High address lines A31–A20 are High during CS-relative memory cycles until an intersegment jump or call is executed (see Section Reset and Initialization).

Physical addresses are formed in Real Mode by adding the contents of the appropriate segment register that is shifted left by 4 bits to an effective address. This addition results in a physical address from 00000000H to 0010FFFFH. This is compatible with 80286 Real Mode. Since segment registers are shifted left by 4 bits, this implies that Real Mode segments always start on 16-byte boundaries.

All segments in Real Mode are exactly 64 Kbytes long and may be read, written, or executed. The Am386DE microprocessor will generate an Exception 13 if a data operand or instruction fetch occurs past the end of a segment (i.e., if an operand has an offset greater than FFFFH; for example, a word with a low byte at FFFFH and the high byte at 0000H).

Segments may be overlapped in Real Mode. Thus, if a particular segment does not use all 64 Kbytes, another segment can be overlaid on top of the unused portion of the previous segment. This allows the programmer to minimize the amount of physical memory needed for a program.

Reserved Locations

There are two fixed areas in memory that are reserved in Real address mode: system initialization area and the interrupt table area. Locations 00000H through 003FFH are reserved for interrupt vectors. Each one of the 256 possible interrupts has a 4-byte jump vector reserved for it. Locations FFFFFFF0H through FFFFFFFFH are reserved for system initialization.

Interrupts

Many of the exceptions shown in Table 5 and discussed in the Interrupts section on page 26 are not applicable to Real Mode operation; in particular, Exceptions 10 and 11 will not happen in Real Mode. Other exceptions have slightly different meanings in Real Mode. Table 11 identifies these exceptions.

Table 11. Other Exceptions In Real Mode

Function	Interrupt Number	Related Instructions	Return Address Location
Interrupt table limit too small	8	INT Vector is not within table limit.	Before Instruction
CS, DS, ES, FS, GS Segment overrun exception	13	Word memory reference beyond offset = FFFFH. An attempt to execute past the end of CS segment.	Before Instruction
SS Segment overrun exception	12	Stack Reference beyond offset = FFFFH.	Before Instruction

Shutdown and Halt

The HLT instruction stops program execution and prevents the processor from using the local bus until restarted. Either NMI, \overline{FLT} , INTR with interrupts enabled (IF = 1), or RESET will force the Am386DE microprocessor out of halt. If interrupted, the saved CS:IP will point to the next instruction after the HLT.

Shutdown will occur when a severe error is detected that prevents further processing. In Real Mode, shutdown can occur under two conditions:

- An interrupt or an exception occurs (Exception 8 or 13) and the interrupt vector is larger than the Interrupt Descriptor Table (i.e., there is not an interrupt handler for the interrupt);
- A CALL, INT, or PUSH instruction attempts to wrap around the stack segment when SP is not even (e.g., pushing a value on the stack when SP = 0001 resulting in a stack segment greater than FFFFH).

An NMI input can bring the processor out of shutdown if the Interrupt Descriptor Table limit is large enough to contain the NMI interrupt vector (at least 0017H) and the stack has enough room to contain the vector and flag information (i.e., SP is greater than 0005H). Otherwise shutdown can only be exited via the RESET input.

PROTECTED MODE ARCHITECTURE

Introduction

The complete capabilities of the Am386DE microprocessor are unlocked when the processor operates in

Protected Address Mode (Protected Mode). Protected Mode vastly increases the physical address space to 4 Gbytes (2^{32} bytes). In addition, Protected Mode allows the Am386DE CPU to run all of the existing 8086 and 80286 software, while providing a sophisticated memory management and a hardware-assisted protection mechanism. Protected Mode allows the use of additional instructions especially optimized for supporting multitasking operating systems. The base architecture of the Am386DE CPU remains the same; the registers, instructions, and addressing modes described in the previous sections are retained. The main differences between Protected Mode and Real Mode from a programmer's view is the increased address space and a different addressing mechanism.

Addressing Mechanism

Like Real Mode, Protected Mode uses two components to form the logical address: a 16-bit selector is used to determine the linear base address of a segment; the base address is added to a 32-bit effective address to form a 32-bit physical address.

The difference between the two modes lies in calculating the base address. In Protected Mode, the selector is used to specify an index into an operating system defined table (see Figure 14). The table contains the 32-bit base address of a given segment. The physical address is formed by adding the base address obtained from the table to the offset.

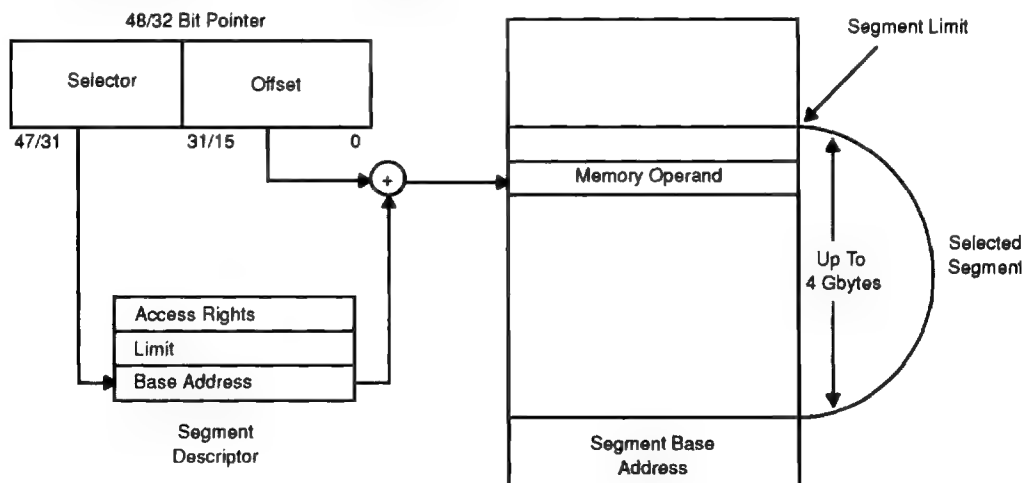


Figure 14. Protected Mode Addressing

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Segmentation

Segmentation Introduction

Segmentation is one method of memory management and provides the basis for protection. Segments are used to encapsulate regions of memory that have common attributes. For example, all of the code of a given program could be contained in a segment or an operating system table may reside in a segment. All information about a segment is stored in an 8-byte data structure called a descriptor. All of the descriptors in a system are contained in tables recognized by hardware.

Terminology

The following terms are used throughout the discussion of descriptors, privilege levels, and protection:

PL: Privilege Level—One of the four hierarchical privilege levels. Level 0 is the most privileged level and level 3 is the least privileged. More privileged levels are numerically smaller than less privileged levels.

RPL: Requester Privilege Level—The privilege level of the original supplier of the selector. RPL is determined by the least two significant bits of a selector.

DPL: Descriptor Privilege Level—This is the least privileged level at which a task may access that descriptor (and the segment associated with that descriptor). Descriptor Privilege Level is determined by bits 6–5 in the Access Right Byte of a descriptor.

CPL: Current Privilege Level—The privilege level at which a task is currently executing, which equals the privilege level of the code segment being executed. CPL

can also be determined by examining the lowest 2 bits of the CS register, except for conforming code segments.

EPL: Effective Privilege Level—The effective privilege level is the least privileged of the RPL and DPL. Since small privilege level values indicate greater privilege, EPL is the numerical maximum of RPL and DPL.

Task: One instance of the execution of a program. Tasks are also referred to as processes.

Descriptor Tables

Descriptor Tables Introduction

The descriptor tables define all of the segments which are used in an Am386DE microprocessor system. There are three types of tables on the Am386DE microprocessor that hold descriptors: the Global Descriptor Table, Local Descriptor Table, and the Interrupt Descriptor Table. All of the tables are variable length memory arrays. They can range in size between 8 bytes and 64 Kbytes. Each table can hold up to 8192 eight byte descriptors. The upper 13 bits of a selector are used as an index into the descriptor table. The tables have registers associated with them that hold the 32-bit base address, and the 16-bit limit of each table.

Each of the tables has a register associated with it: the GDTR, LDTR, and the IDTR (see Figure 15). The LGDT, LLDT, and LIDT instructions load the base and limit of the Global, Local, and Interrupt Descriptor Tables, respectively, into the appropriate register. The SGDT, SLDT, and SIDT instructions store the base and limit values. These tables are manipulated by the operating system. Therefore, the load descriptor table instructions are privileged instructions.

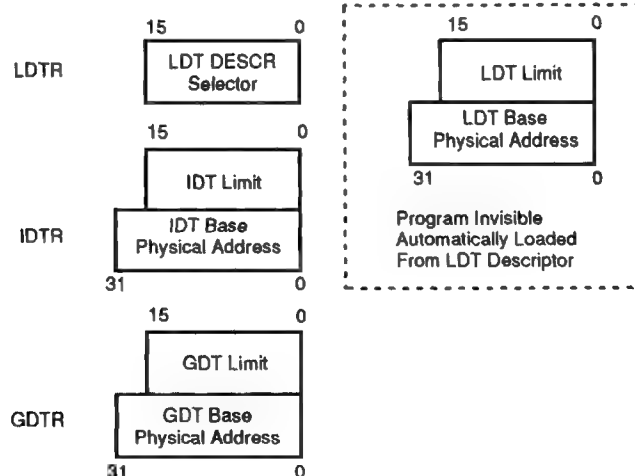


Figure 15. Descriptor Table Registers

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Global Descriptor Table

The Global Descriptor Table (GDT) contains descriptors that are possibly available to all of the tasks in a system. The GDT can contain any type of segment descriptor except for descriptors that are used for servicing interrupts (i.e., interrupt and trap descriptors). Every Am386DE microprocessor contains a GDT. Generally, the GDT contains code and data segments used by the operating systems and task state segments and descriptors for the LDTs in a system.

The first slot of the Global Descriptor Table corresponds to the null selector and is not used. The null selector defines a null pointer value.

Local Descriptor Table

LDTs contain descriptors that are associated with a given task. Generally, operating systems are designed so that each task has a separate LDT. The LDT may contain only code, data, stack, task gate, and call gate descriptors. LDTs provide a mechanism for isolating a given task's code and data segments from the rest of the operating system, while the GDT contains descriptors for segments that are common to all tasks. A segment cannot be accessed by a task if its segment descriptor does not exist in either the current LDT or the GDT. This provides both isolation and protection for a task's segments, while still allowing global data to be shared among tasks.

Unlike the 6-byte GDT or IDT registers that contain a base address and limit, the visible portion of the LDT register contains only a 16-bit selector. This selector refers to a Local Descriptor Table descriptor in the GDT.

Interrupt Descriptor Table

The third table needed for Am386DE microprocessor systems is the Interrupt Descriptor Table (see Figure 16). The IDT contains the descriptors that point to the location of up to 256 interrupt service routines. The IDT may contain only task gates, interrupt gates, and trap gates. The IDT should be at least 256 bytes in size in order to hold the descriptors for the 32, Reserved for Future Use, interrupts. Every interrupt used by a system must have an entry in the IDT. The IDT entries are referenced via INT instructions, external interrupt vectors, and exceptions. (See the Interrupts section on page 26.)

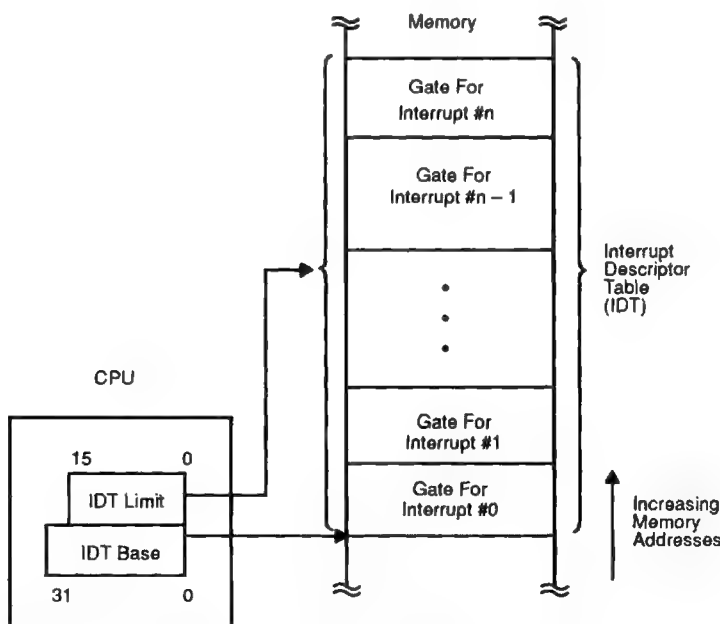


Figure 16. Interrupt Descriptor Table Register Use

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Descriptors

Descriptor Attribute Bits

The object to which the segment selector points is called a descriptor. Descriptors are 8-byte quantities that contain attributes about a given region of physical address space (i.e., a segment). These attributes include the 32-bit base physical address of the segment, the 20-bit length and granularity of the segment, the protection level, read, write, or execute privileges, the default size of the operands (16 bit or 32 bit), and the type of segment. All of the attribute information about a segment is contained in 12 bits in the segment descriptor. Figure 17 shows the general format of a descriptor. All segments on the Am386DE microprocessor have three attribute fields in common: the P bit, the DPL bit, and the S bit. The Present P bit is 1 if the segment is loaded in physical memory; if P = 0 then any attempt to access this segment causes a not present exception (Exception 11). The Descriptor Privilege Level (DPL) is a 2-bit field that specifies the protection levels 0–3 associated with a segment.

The Am386DE microprocessor has two main categories of segments: system segments and non-system segments (for code and data). The segment S bit in the segment descriptor determines if a given segment is a system segment or a code or data segment. If the S bit is 1, then the segment is either a code or data segment; if it is 0, then the segment is a system segment.

Am386DE Microprocessor Code and Data Descriptors (S = 1)

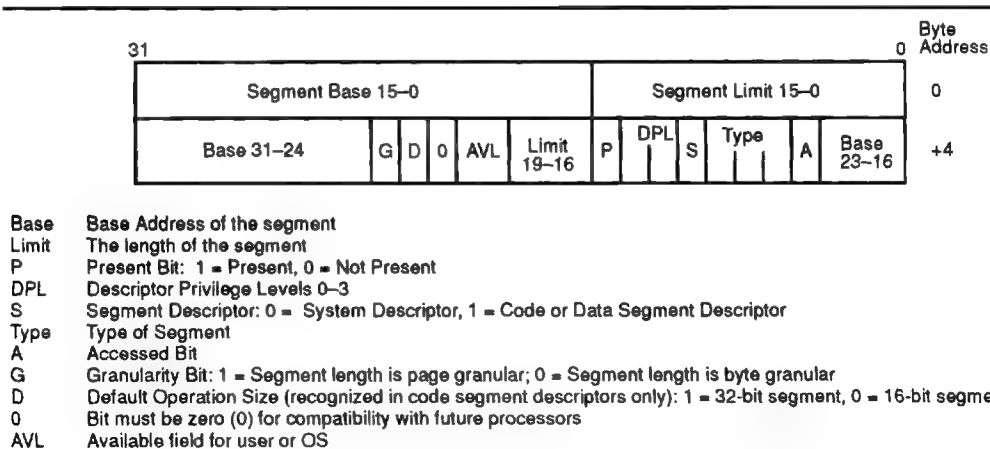
Figure 18 shows the general format of a code and data descriptor and Table 12 illustrates how the bits in the Access Rights Byte are interpreted.

Code and data segments have several descriptor fields in common. The accessed A bit is set whenever the processor accesses a descriptor. The A bit is used by operating systems to keep usage statistics on a given segment. The G bit, or granularity bit, specifies if a segment length is byte-granular or page-granular. Am386DE microprocessor segments can be 1 Mbyte long with byte granularity (G = 0) or 4 Gbytes with page granularity (G = 1), (i.e., 2^{20} pages—each page is 4 Kbytes in length). An Am386DE CPU system can consist of segments with byte granularity and page granularity.

The executable E bit tells if a segment is a code or data segment. A code segment (E = 1, S = 1) may be execute-only or execute/read as determined by the Read R bit. Code segments are execute only if R = 0 and execute/read if R = 1. Code segments may never be written into.

Note: Code segments may be modified via aliases. Aliases are writeable data segments that occupy the same range of physical address space as the code segment.

The D bit indicates the default length for operands and effective addresses. If D = 1, then 32-bit operands and 32-bit addressing modes are assumed. If D = 0, then

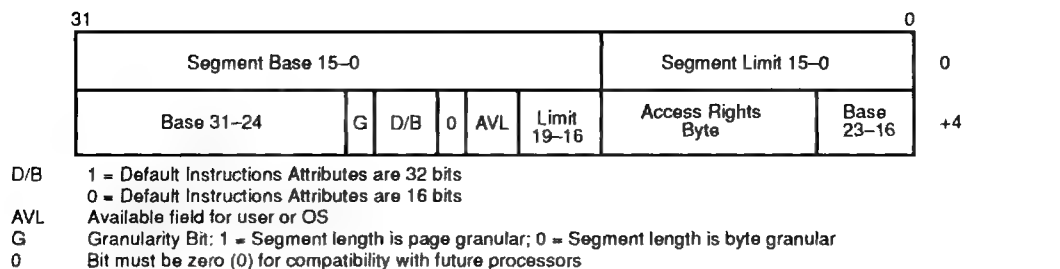


Note:

In a maximum-size segment (i.e., segment with G = 1 and segment limit 19–0 = FFFFFH), the lowest 12 bits of the segment base should be zero (i.e., segment base 11–000 = 000H).

Figure 17. General Format of Segment Descriptors

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Note:

In a maximum-size segment (i.e., a segment with $G = 1$ and segment limit $19-0 = \text{FFFFFH}$), the lowest 12 bits of the segment base should be zero (i.e., segment base $11-000 = 000H$).

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Figure 18. Code and Data Segment Descriptors

Table 12. Access Rights Byte Definition for Code and Data Descriptions

Bit Position	Name	Function
7	Present (P)	P = 1 Segment is mapped into physical memory. P = 0 No mapping to physical memory exists, base and limit are not used.
6-5	Descriptor Privilege Levels (DPL)	Segment privilege attribute used in privilege tests.
4	Segment Descriptor (S)	S = 1 Code or Data (includes stacks) segment descriptor. S = 0 System Segment Descriptor or Gate Descriptor.
3	Executable (E)	E = 0 Descriptor type is data segment.
2	Expansion Direction (ED)	ED = 0 Expand up segment, offsets must be \leq limit. ED = 1 Expand down segment, offsets must be $>$ limit.
1	Writeable (W)	W = 0 Data segment may not be written into. W = 1 Data segment may be written into.
3	Executable (E)	E = 1 Descriptor type is code segment.
2	Conforming (C)	C = 1 Code segment may only be executed when $\text{CPL} \geq \text{DPL}$ and CPL remains unchanged.
1	Readable (R)	R = 0 Code segment may not be read. R = 1 Code segment may be read.
0	Accessed (A)	A = 0 Segment has not been accessed. A = 1 Segment selector has been loaded into segment register or used by selector test instructions.

16-bit operands and 16-bit addressing modes are assumed. Therefore all existing 80286 code segments will execute on the Am386DE microprocessor assuming the D bit is set 0.

Another attribute of code segments is determined by the conforming C bit. Conforming segments, $C = 1$, can be executed and shared by programs at different privilege levels (see the Protection section on page 45).

Segments identified as data segments ($E = 0$, $S = 1$) are used for two types of Am386DE microprocessor segments: stack and data segments. The expansion direction (ED) bit specifies if a segment expands downward (stack) or upward (data). If a segment is a stack segment, all offsets must be greater than the segment

limit. On a data segment all offsets must be less than or equal to the limit. In other words, stack segments start at the base physical address plus the maximum segment limit and grow down to the base physical address plus the limit. On the other hand, data segments start at the base physical address and expand to the base physical address plus limit.

The write (W) bit controls the ability to write into a segment. Data segments are read-only if $W = 0$. The stack segment must have $W = 1$.

The B bit controls the size of the stack pointer register. If $B = 1$, then PUSHes, POPs, and CALLs all use the 32-bit ESP register for stack references and assume an upper limit of FFFFFFFFH. If $B = 0$, stack instructions

all use the 16-bit SP register and assume an upper limit of FFFFH.

System Descriptor Formats

System segments describe information about operating system tables, tasks, and gates. Figure 19 shows the general format of system segment descriptors, and the various types of system segments. The Am386DE microprocessor system descriptors contain a 32-bit base physical address and a 20-bit segment limit. 80286 system descriptors have a 24-bit base address and a 16-bit segment limit. 80286 system descriptors are identified by the upper 16 bits being all zeros.

LDT Descriptors (S = 0, Type = 2)

LDT descriptors (S = 0, TYPE = 2) contain information about Local Descriptor Tables. LDTs contain a table of segment descriptors, unique to a particular task. Since the instruction to load the LDTR is only available at privilege level 0, the DPL field is ignored. LDT descriptors are only allowed in the Global Descriptor Table (GDT).

TSS Descriptors (S = 0, Type = 1, 3, 9, B)

A Task State Segment (TSS) descriptor contains information about the location, size, and privilege level of a TSS. A TSS in turn is a special fixed format segment that contains all the state information for a task and a linkage field to permit nesting tasks. The Type field is used to indicate whether the task is currently BUSY (i.e., on a chain of active tasks) or the TSS is available. The Type field also indicates if the segment contains a 80286 or an Am386DE microprocessor TSS. The Task Register (TR) contains the selector that points to the current TSS.

Gate Descriptors (S = 0, Type = 4–7, C, F)

Gates are used to control access to entry points within the target code segment. The various types of gate

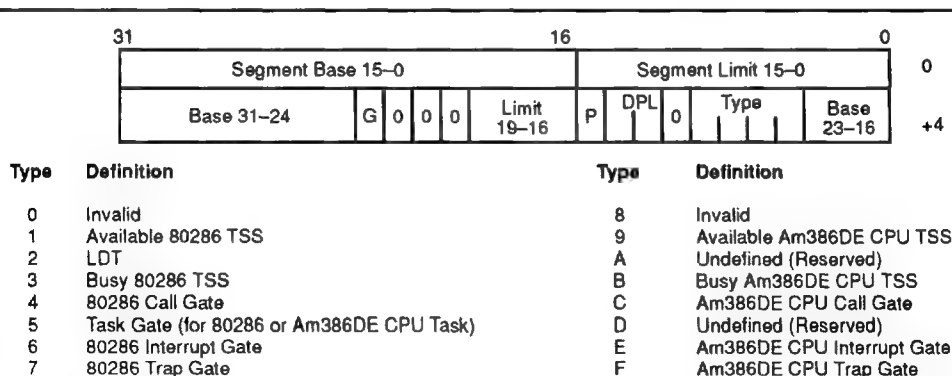
descriptors are call gates, task gates, interrupt gates, and trap gates. Gates provide a level of indirection between the source and destination of the control transfer. This indirection allows the processor to automatically perform protection checks. It also allows system designers to control entry points to the operating system. Call gates are used to change privilege levels (see the Protection section on page 45), task gates are used to perform a task switch, and interrupt and trap gates are used to specify interrupt service routines.

Figure 20 shows the format of the four types of gate descriptors. Call gates are primarily used to transfer program control to a more privileged level. The call gate descriptor consists of three fields: the access byte; a long pointer (selector and offset) that points to the start of a routine; and a word count that specifies how many parameters are to be copied from the caller's stack to the stack of the called routine. The word count field is only used by call gates when there is a change in the privilege level, other types of gates ignore the word count field.

Interrupt and trap gates use the destination selector and destination offset fields of the gate descriptor as a pointer to the start of the interrupt or trap handler routines. The difference between interrupt gates and trap gates is that the interrupt gate disables interrupts (resets the IF bit) while the trap gate does not.

Task gates are used to switch tasks. Task gates may only refer to a task state segment (see the Task Switching section on page 49); therefore, only the destination selector portion of a task gate descriptor is used, and the destination offset is ignored.

Exception 13 is generated when a destination selector does not refer to a correct descriptor type (i.e., a code

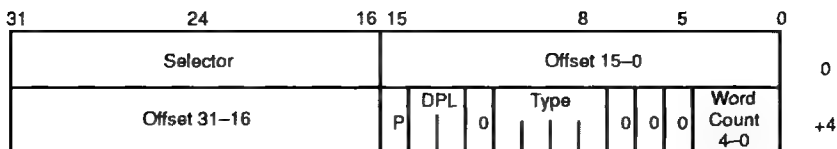


Note:

In a maximum-size segment (i.e., segment with G = 1 and segment limit 19–0 = FFFFFH), the lowest 12 bits of the segment base should be zero (i.e., segment base 11–000 = 000H).

Figure 19. System Segments Descriptors

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Gate Descriptors Fields

Name	Value	Description
Type	4	80286 Call Gate
	5	Task Gate (for 80286 or Am386DE CPU Task)
	6	80286 Interrupt Gate
	7	80286 Trap Gate
	C	Am386DE CPU Call Gate
	E	Am386DE CPU Interrupt Gate
	F	Am386DE CPU Trap Gate
P	0	Descriptor contents are not valid
	1	Descriptor contents are valid

DPL—Least privileged level at which a task may access the gate. WORD COUNT 0–31—The number of parameters to copy from caller's stack to the called procedure's stack. The parameters are 32-bit quantities for Am386DE CPU gates, and 16-bit quantities for 80286 gates.

DESTINATION SELECTOR	16-Bit Selector	Selector to the target code segment or Selector to the target state segment for task gate
DESTINATION OFFSET	Offset 16-bit 80286 32-bit Am386DE CPU	Entry point within the target code segment

Figure 20. Gate Descriptor Formats

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segment for an interrupt, trap, or call gate, a TSS for a task gate).

The access byte format is the same for all gate descriptors. P = 1 indicates that the gate contents are valid. P = 0 indicates the contents are not valid and causes Exception 11 if referenced. DPL is the descriptor privilege level and specifies when this descriptor may be used by a task (see the Protection section on page 45). The S field, bit 4 of the access rights byte, must be 0 to indicate a system control descriptor. The type field specifies the descriptor type as indicated in Figure 20.

Difference Between Am386DE Microprocessor and 80286 Descriptors

In order to provide operating system compatibility between the 80286 and Am386DE microprocessor, the Am386DE CPU supports all of the 80286 segment descriptors. Figure 21 shows the general format of an 80286 system segment descriptor. The only differences between 80286 and Am386DE device descriptor formats are that the values of the type fields and the limit and base address fields have been expanded for the Am386DE device. The 80286 system segment descriptors contained a 24-bit base address and 16-bit limit, while the Am386DE microprocessor system segment

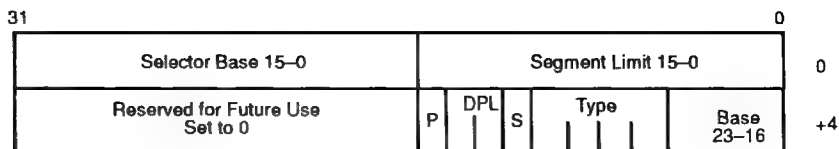
descriptors have a 32-bit base address, a 20-bit limit field, and a granularity bit.

By supporting 80286 system segments, the Am386DE microprocessor is able to execute 80286 application programs on an Am386DE CPU operating system. This is possible because the processor automatically understands which descriptors are 80286-style descriptors and which are Am386DE microprocessor-style descriptors. In particular, if the upper word of a descriptor is zero, then that descriptor is an 80286-style descriptor.

The only other differences between 80286-style descriptors and Am386DE microprocessor descriptors is the interpretation of the word count field of call gates and the B bit. The word count field specifies the number of 16-bit quantities to copy for 80286 call gates and 32-bit quantities for Am386DE device call gates. The B bit controls the size of PUSHes when using a call gate; if B = 0, then PUSHes are 16 bits, if B = 1, then PUSHes are 32 bits.

Selector Fields

A selector in Protected Mode has three fields: Local or Global Descriptor Table Indicator (TI), Descriptor Entry Index (Index), and Requestor (the selector's) Privilege Level (RPL) as shown in Figure 22. The TI bits select



Base Base Address of the Segment
 Limit The length of the Segment
 P Present Bit: 1 = Present, 0 = Not Present
 DPL Descriptor Privilege Levels 0-3
 S System Descriptor: 0 = System, 1 = User
 Type Type of Segment

Figure 21. 80286 Code and Data Segment Descriptors

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one of two memory-based tables of descriptors (the Global Descriptor Table or the Local Descriptor Table). The Index selects one of 8K descriptors in the appropriate descriptor table. The RPL bits allow high speed testing of the selector's privilege attributes.

Segment Descriptor Cache

In addition to the selector value, every segment register has a segment descriptor cache register associated with it. Whenever a segment register's contents are changed, the 8-byte descriptor associated with that selector is automatically loaded (cached) on the chip. Once loaded, all references to that segment use the cached descriptor information instead of reaccessing

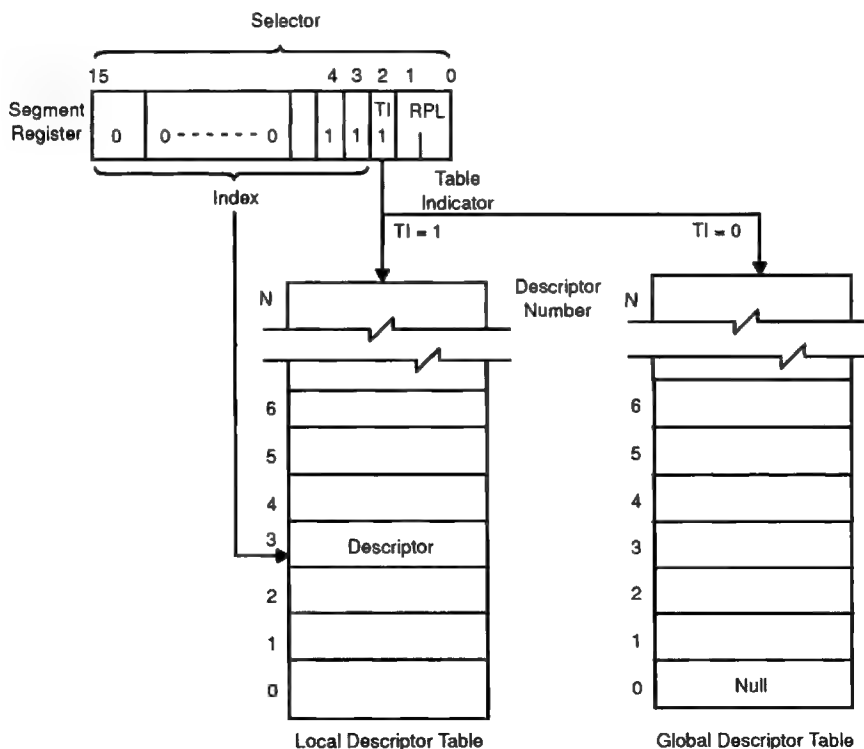


Figure 22. Example Descriptor Selection

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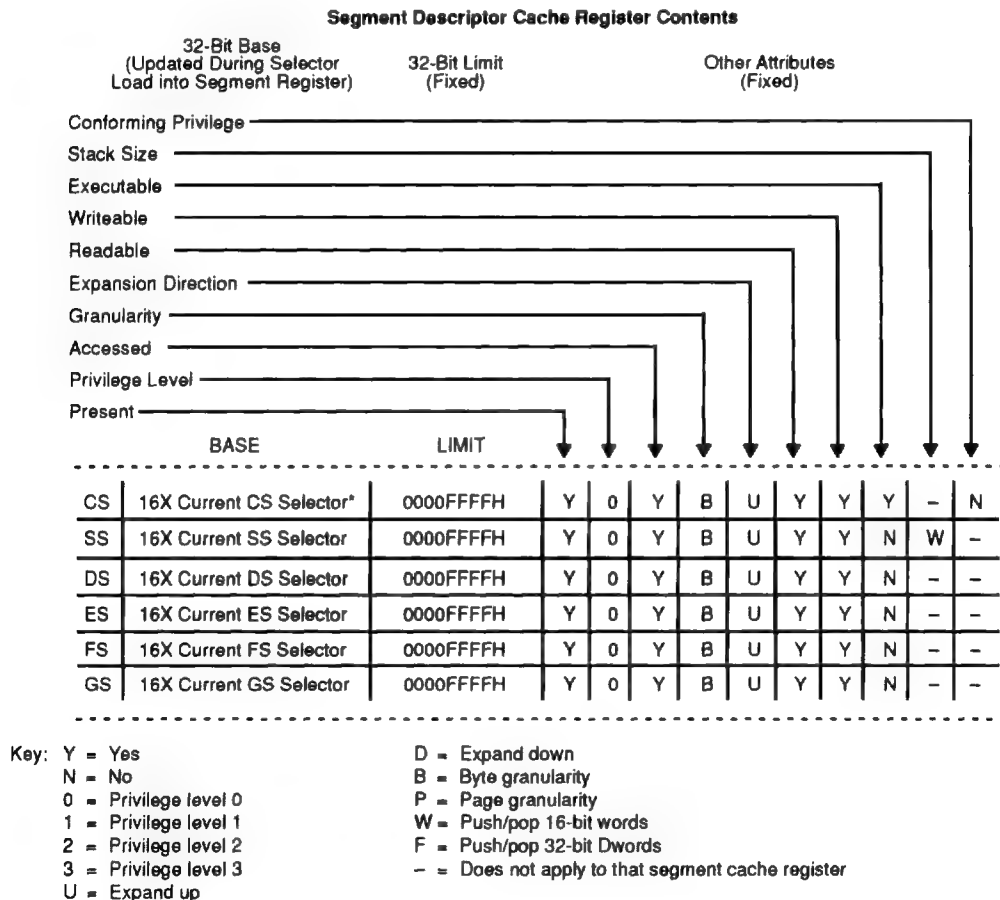
the descriptor. The contents of the descriptor cache are not visible to the programmer. Since descriptor caches only change when a segment register is changed, programs that modify the descriptor tables must reload the appropriate segment registers after changing a descriptor's value.

Segment Descriptor Register Settings

The contents of the segment descriptor cache vary depending on the operating mode of the Am386DE microprocessor. When operating in Real Address Mode, the segment base, limit, and other attributes within the segment cache registers are defined as shown in Figure 23.

For compatibility with the 8086 architecture, the base is set to 16 times the current selector value, the limit is fixed at 0000FFFFH, and the attributes are fixed to indicate that the segment is present and fully usable. In Real Address Mode, the internal privilege level is always fixed to the highest level, level 0, so I/O and other privileged op-codes may be executed.

When operating in Protected Mode, the segment base, limit, and other attributes within the segment cache registers are defined as shown in Figure 24. In Protected Mode, each of these fields are defined according to the contents of the segment descriptor indexed by the selector value loaded into the segment register.



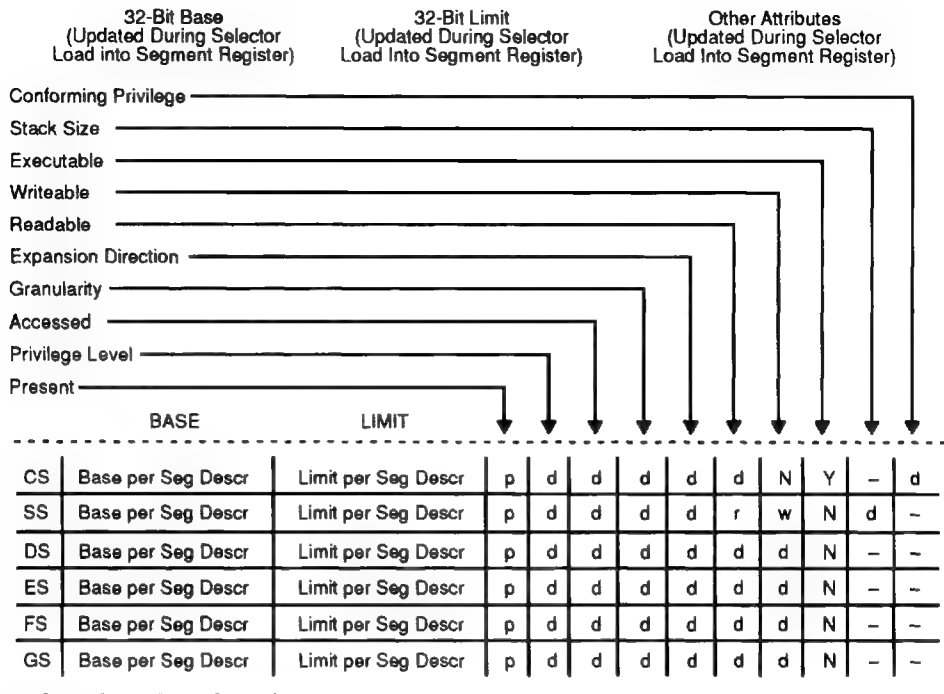
Note:

*Except the 32-bit CS base is initialized to FFFF000H after reset until first intersegment control transfer (e.g., intersegment CALL, or intersegment JMP, or INT).

**Figure 23. Segment Descriptor Caches for Real Address Mode
(Segment Limit and Attributes are Fixed)**

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Segment Descriptor Cache Register Contents



Key: Y = Fixed Yes

N = Fixed No

d = Per segment descriptor

p = Per segment descriptor; descriptor must indicate "present" to avoid Exception 11 (Exception 12 in case of SS)

r = Per segment descriptor, but descriptor must indicate "readable" to avoid Exception 13 (special case for SS)

w = Per segment descriptor, but descriptor must indicate "writeable" to avoid Exception 13 (special case for SS)

- = Does not apply to that segment cache register

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Figure 24. Segment Descriptor Caches for Protected Mode (Loaded per Descriptor)

Protection

Protection Concepts

The Am386DE microprocessor has four levels of protection that are optimized to support the needs of a multitasking operating system to isolate and protect user programs from each other and the operating system. The privilege levels control the use of privileged instructions, I/O instructions, and access to segments and segment descriptors.

The four-level hierarchical privilege system is illustrated in Figure 25. It is an extension of the user/supervisor privilege mode commonly used by minicomputers. The privilege levels (PL) are numbered 0 through 3. Level 0 is the most privileged or trusted level.

Rules of Privilege

The Am386DE microprocessor controls access to both data and procedures between levels of a task, according to the following rules.

- Data stored in a segment with privilege level p can be accessed only by code executing at a privilege level at least as privileged as p.
- A code segment/procedure with privilege level p can only be called by a task executing at the same or a lesser privilege level than p.

Privilege Levels

Task Privilege

At any point in time, a task on the Am386DE microprocessor always executes at one of the four privilege levels. The Current Privilege Level (CPL) specifies the task's privilege level. A task's CPL may only be changed by control transfers through gate descriptors to a code

segment with a different privilege level (see the Privilege Level Transfers section on page 49). Thus, an application program running at PL = 3 may call an operating system routine at PL = 1 (via a gate) that would cause the task's CPL to be set to 1 until operating system routine is finished.

Selector Privilege (RPL)

The privilege level of a selector is specified by the RPL field. The RPL is the two least significant bits of the selector. The selector's RPL is only used to establish a less trusted privilege level than the current privilege level for the use of a segment. This level is called the task's effective privilege level (EPL). The EPL is defined as being the least privileged (i.e., numerically larger) level of a task's CPL and a selector's RPL. Thus, if selector's RPL = 0, then the CPL always specifies the privilege level for making an access using the selector. On the other hand if RPL = 3, then a selector can only access segments at level 3 regardless of the task's CPL. The RPL is most commonly used to verify that pointers passed to an operating system procedure do not access data that is of higher privilege than the procedure that originated the pointer. Since the originator of a selector can specify any RPL value, the Adjust RPL (ARPL) instruction is provided to force the RPL bits to the originator's CPL.

I/O Privilege and I/O Permission Bitmap

The I/O privilege level (IOPL, a 2-bit field in the EFLAGS register) defines the least privileged level at which I/O instructions can be unconditionally performed. I/O instructions can be unconditionally performed when $CPL \leq IOPL$. (The I/O instructions are IN, OUT, INS,

OUTS, REP INS, and REP OUTS.) When $CPL > IOPL$, and the current task is associated with a 286 TSS, attempted I/O instructions cause an Exception 13 fault. When $CPL > IOPL$, and the current task is associated with an Am386DE CPU TSS, the I/O Permission Bitmap (part of an Am386DE microprocessor TSS) is consulted on whether I/O to the port is allowed, or an Exception 13 fault is to be generated instead. For diagrams of the I/O Permission Bitmap, refer to Figure 26. For further information on how the I/O Permission Bitmap is used in Protected Mode, refer to the Protection section on page 45 and I/O Permission Bitmap section on page 46.

The IOPL privilege level (IOPL) also affects whether several other instructions can be executed or cause an Exception 13 fault instead. These instructions are called IOPL-sensitive instructions and they are CLI and STI. (Note that the LOCK prefix is not IOPL-sensitive on the Am386DE microprocessor.)

The IOPL also affects whether the IF bit (interrupts enable flag) can be changed by loading a value into the EFLAGS register. When $CPL \leq IOPL$, the IF bit can be changed by loading a new value into the EFLAGS register. When $CPL > IOPL$, the IF bit cannot be changed by a new value POP'ed into (or otherwise loaded into) the EFLAGS register; the IF bit merely remains unchanged and no exception is generated.

Privilege Validation

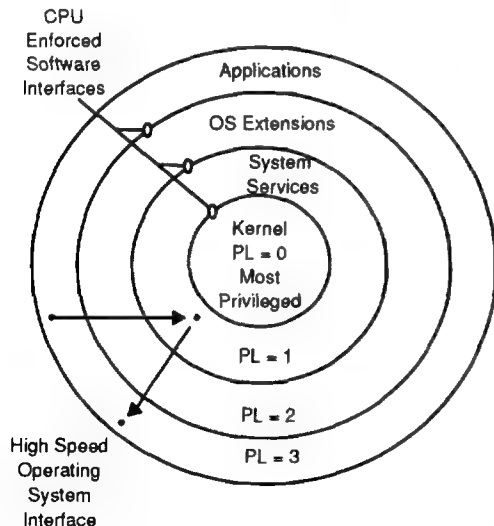
The Am386DE CPU provides several instructions to speed pointer testing and help maintain system integrity by verifying that the selector value refers to an appropriate segment. Table 13 summarizes the selector validation procedures available for the Am386DE microprocessor.

This pointer verification prevents the common problem of an application at PL = 3 calling an operating-systems routine at PL = 0 and passing the operating-systems routine a bad pointer that corrupts a data structure belonging to the operating system. If the operating-systems routine uses the ARPL instruction to ensure that the RPL of the selector has no greater privilege than that of the caller, then this problem can be avoided.

Descriptor Access

There are basically two types of segment accesses: those involving code segments, such as control transfers; and those involving data accesses. Determining the ability of a task to access a segment involves the type of segment to be accessed, the instruction used, the type of descriptor used, and CPL, RPL, and DPL as described above.

Any time an instruction loads data segment registers (DS, ES, FS, GS) the Am386DE microprocessor makes protection validation checks. Selectors loaded in the DS, ES, FS, GS registers must refer only to data segments or readable code segments. The data access rules are specified in the Rules of Privilege section. The



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Figure 25. Four-Level Hierarchical Protection

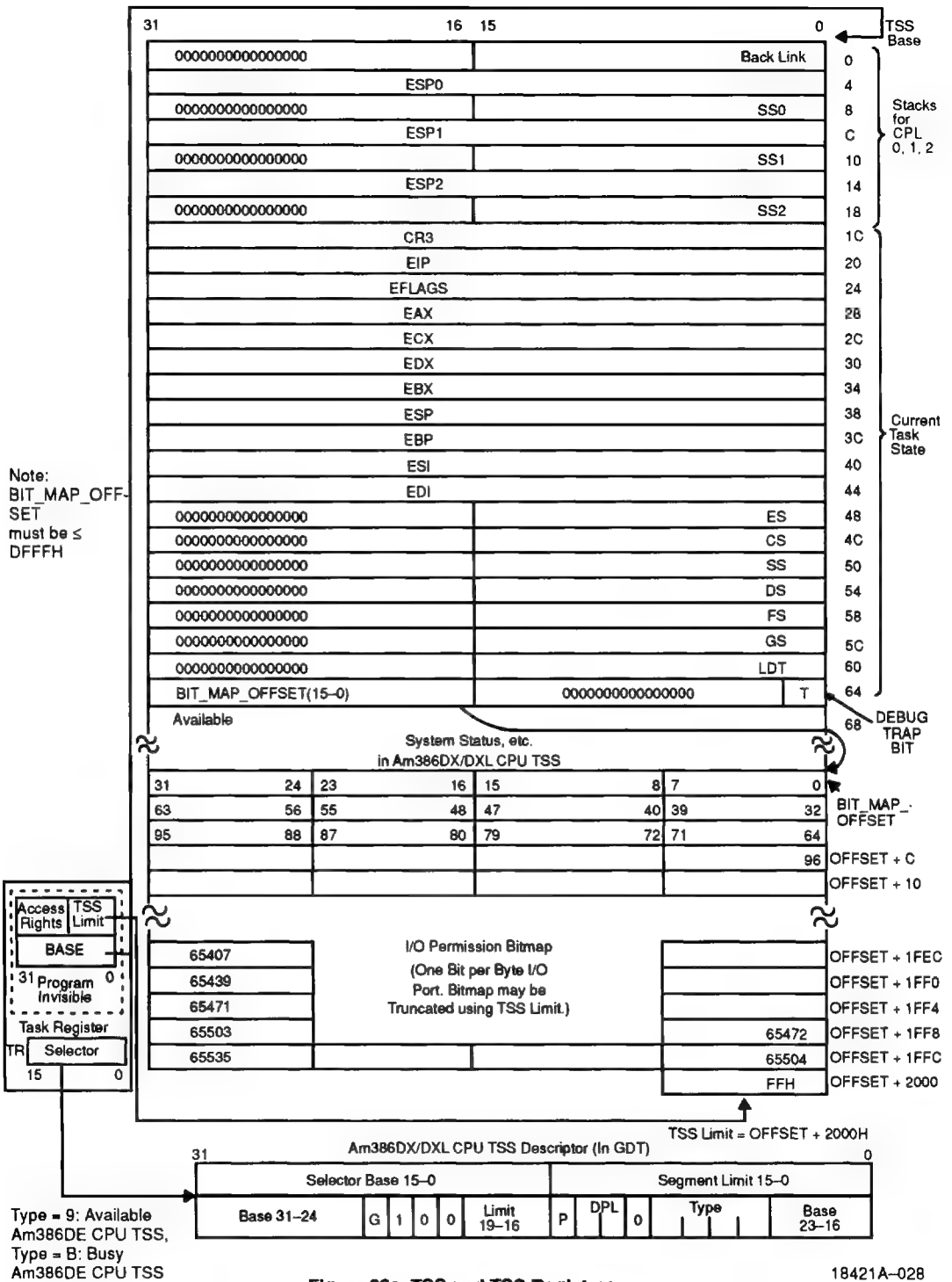


Figure 26a. TSS and TSS Registers

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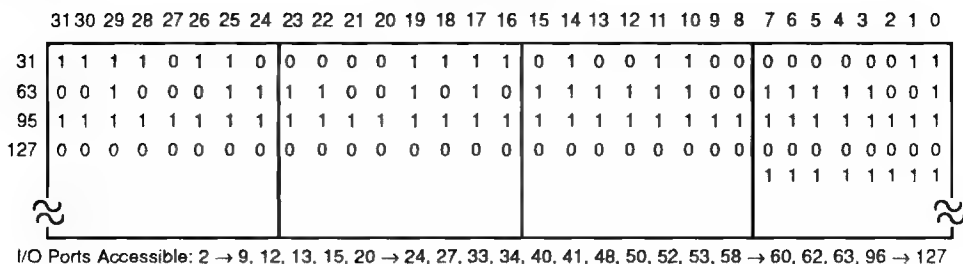


Figure 26b. Sample I/O Permission Bit Map

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only exception to those rules is readable conforming code segments which can be accessed at any privilege level.

Finally, the privilege validation checks are performed. The CPL is compared to the EPL; if the EPL is more privileged than the CPL, an Exception 13 (General Protection fault) is generated.

The rules regarding the stack segment are slightly different than those involving data segments. Instructions that load selectors into SS must refer to data segment descriptors for writable data segments. The DPL and RPL must equal the CPL. All other descriptor types or a privilege level violation will cause Exception 13. A stack not present fault causes Exception 12. Note that an Exception 11 is used for a not-present code or data segment.

Privilege Level Transfers

Intersegment control transfers occur when a selector is loaded in the CS register. For a typical system most of

these transfers are simply the result of a call or a jump to another routine. There are five types of control transfers, which are summarized in Table 14.

Many of these transfers result in a privilege level transfer. Changing privilege levels is done only via control transfers by using gates, task switches, and interrupt or trap gates.

Control transfers can only occur if the operation that loaded the selector references the correct descriptor type. Any violation of these descriptor usage rules will cause an Exception 13 (e.g., JMP through a call gate or IRET from a normal subroutine call).

In order to provide further system security, all control transfers are also subject to the privilege rules.

The privilege rules require that:

1. Privilege level transitions can only occur via gates.
2. JMPs can be made to a non-conforming code segment with the same privilege or to a conforming code segment with greater or equal privilege.
3. CALLs can be made to a non-conforming code segment with the same privilege or via a gate to a more privileged level.
4. Interrupts handled within the task obey the same privilege rules as CALLs.
5. Conforming Code segments are accessible by privilege levels that are the same or less privileged than the conforming-code segment's DPL.
6. Both the requested privilege level (RPL) in the selector pointing to the gate and the task's CPL must be of equal or greater privilege than the gate's DPL.
7. The code segment selected in the gate must be the same or more privileged than the task's CPL.
8. Return instructions that do not switch tasks can only return control to a code segment with same or less privilege.
9. Task switches can be performed by a CALL, JMP, or INT that references either a task gate or task state segment whose DPL is less privileged or the same privilege as the old task's CPL.

Table 13. Pointer Test Instructions

Instruction	Operands	Function
ARPL	Selector, Register	Adjust Requested Privilege Level; adjusts the RPL of the selector to the numeric maximum of current selector RPL value and the RPL value in the register. Set zero flag if selector RPL was changed.
VERR	Selector	VERify for Read: sets the zero flag if the segment referred to by the selector can be read.
VERW	Selector	VERify for Write: sets the zero flag if the segment referred to by the selector can be written.
LSL	Register, Selector	Load Segment Limit: reads the segment limit into the register if privilege rules and descriptor type allow. Set zero flag if successful.
LAR	Register, Selector	Load Access Rights: reads the descriptor access rights byte into the register if privilege rules allow. Set zero flag if successful.

Any control transfer that changes CPL within a task causes a change of stacks as a result of the privilege level change. The initial values of SS:ESP for privilege levels 0, 1, and 2 are retained in the task state segment (see the Task Switching section). During a JMP or CALL control transfer, the new stack pointer is loaded in the SS and ESP registers and the previous stack pointer is pushed onto the new stack.

When returning to the original privilege level, use of the lower-privilege stack is restored as part of the RET or IRET instruction operation. For subroutine calls that pass parameters on the stack and cross privilege levels, a fixed number of words (as specified in the gate's word count field) are copied from the previous stack to the current stack. The intersegment RET instruction with a stack adjustment value will correctly restore the previous stack pointer upon return.

Call Gates

Gates provide protected, indirect CALLs. One of the major uses of gates is to provide a secure method of privilege transfers within a task. Since the operating system defines all the gates in a system, it can ensure that all gates only allow entry into a few trusted procedures (such as those that allocate memory or perform I/O).

Gate descriptors follow the data access rules of privilege; that is, gates can be accessed by a task if the CPL is equal to or more privileged than the gate descriptor's DPL. Gates follow the control transfer rules of privilege and therefore may only transfer control to a more privileged level.

Call gates are accessed via a CALL instruction and are syntactically identical to calling a normal subroutine. When an interlevel Am386DE microprocessor call gate is activated, the following actions occur:

1. Load CS:EIP from gate check for validity;
2. SS is pushed zero-extended to 32 bits;
3. ESP is pushed;
4. Copy word count 32-bit parameters from the old stack to the new stack;
5. Push return address on stack.

The procedure is identical for 80286 Call gates, except that 16-bit parameters are copied and 16-bit registers are pushed.

Interrupt gates and Trap gates work in a similar fashion as the call gates, except there is no copying of parameters. The only difference between Trap and Interrupt gates is that control transfers through an Interrupt gate disable further interrupts (i.e., the IF bit is set to 0) and Trap gates leave the interrupt status unchanged.

Task Switching

A very important attribute of any multitasking/multi-user operating system is its ability to rapidly switch between tasks or processes. The Am386DE microprocessor directly supports this operation by providing a task switch instruction in hardware. The Am386DE CPU task switch operation saves the entire state of the machine (all of the registers, address space, and a link to the previous task), loads a new execution state, performs protection checks, and commences execution in the new task, in about 17 ms. Like transfer of control via gates, the task switch operation is invoked by executing an intersegment JMP or CALL instruction that refers to a Task State Segment (TSS), or a task gate descriptor in the GDT or LDT. An INTn instruction, exception, trap, or external interrupt may also invoke the task switch operation if there is a task gate descriptor in the associated IDT descriptor slot.

Table 14. Descriptor Types Used for Control Transfer

Control Transfer Types	Operation Types	Descriptor Referenced	Descriptor Table
Intersegment within the same privilege level	JMP, CALL, RET, IRET*	Code Segment	GDT/LDT
Intersegment to the same or higher privilege level	CALL	Call Gate	GDT/LDT
Interrupt within task may change CPL	Interrupt Instruction, Exception, External Interrupt	Trap or Interrupt Gate	IDT
Intersegment to a lower privilege level (change task CPL)	RET, IRET*	Code Segment	GDT/LDT
	CALL, JMP	Task State Segment	GDT
Task Switch	CALL, JMP	Task Gate	GDT/LDT
	IRET**, Interrupt Instruction, Exception, External Interrupt	Task Gate	IDT

Note:

*NT (Nested Task bit of flag register) = 0

**NT (Nested Task bit of flag register) = 1

The TSS descriptor points to a segment (see Figure 26a) containing the entire Am386DE microprocessor execution state while a task gate descriptor contains a TSS selector. The Am386DE CPU supports both 80286 and Am386DE CPU style TSSs. Figure 27 shows an 80286 TSS. The limit of an Am386DE microprocessor TSS must be greater than 0064H (002BH for an 80286 TSS) and can be as large as 4 Gbytes. In the additional TSS space, the operating system is free to store additional information, such as the reason the task is inactive, time the task has spent running, and open files belonging to the task.

Each task must have a TSS associated with it. The current TSS is identified by a special register in the Am386DE microprocessor called the Task State Segment Register (TR). This register contains a selector referring to the task state segment descriptor that defines the current TSS. A hidden base and limit register associated with TR are loaded whenever TR is loaded with a new selector. Returning from a task is accomplished by the IRET instruction. When IRET is executed, control is returned to the task that was interrupted. The current executing task's state is saved in the TSS and the old task state is restored from its TSS.

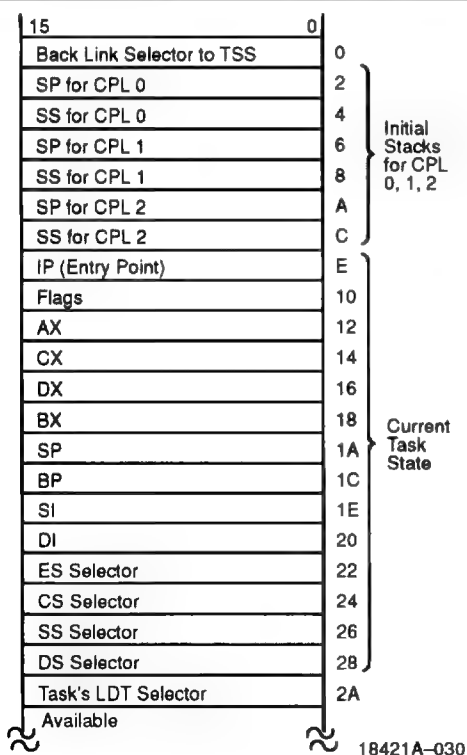


Figure 27. 80286 TSS

Several bits in the flag register and machine status word (CR0) give information about the state of a task that is useful to the operating system. The Nested Task (NT) (bit 14 in EFLAGS) controls the function of the IRET instruction. If NT = 0, the IRET instruction performs the regular return; when NT = 1, IRET performs a task switch operation back to the previous task. The NT bit is set or reset in the following fashion.

When a CALL or INT instruction initiates a task switch, the new TSS will be marked busy and the back link field of the new TSS set to the old TSS selector. The NT bit of the new task is set by CALL or INT initiated task switches. An interrupt that does not cause a task switch will clear NT. (The NT bit will be restored after execution of the interrupt handler.) NT may also be set or cleared by POPF or IRET instructions.

The Am386DE microprocessor Task State Segment is marked busy by changing the descriptor type field from Type 9H to Type BH. An 80286 TSS is marked busy by changing the descriptor type field from Type 1 to Type 3. Use of a selector that references a busy task state segment causes an Exception 13.

The coprocessor's state is not automatically saved when a task switch occurs, because the incoming task may not use the coprocessor. The Task Switched (TS) Bit (bit 3 in the CR0) helps deal with the coprocessor's state in a multitasking environment. Whenever the Am386DE microprocessor switches tasks, it sets the TS bit. The Am386DE CPU detects the first use of a processor extension instruction after a task switch and causes the processor extension not available Exception 7. The exception handler for Exception 7 may then decide whether to save the state of the coprocessor. A processor extension not present Exception 7 will occur when attempting to execute an ESC or WAIT instruction if the Task Switched and Monitor coprocessor extension bits are both set (i.e., TS = 1 and MP = 1).

The T bit in the Am386DE microprocessor TSS indicates that the processor should generate a debug exception when switching to a task. If T = 1, then upon entry to a new task, a debug Exception 1 will be generated.

Initialization and Transition to Protected Mode

Since the Am386DE microprocessor begins executing in Real Mode immediately after RESET, it is necessary to initialize the system tables and registers with the appropriate values.

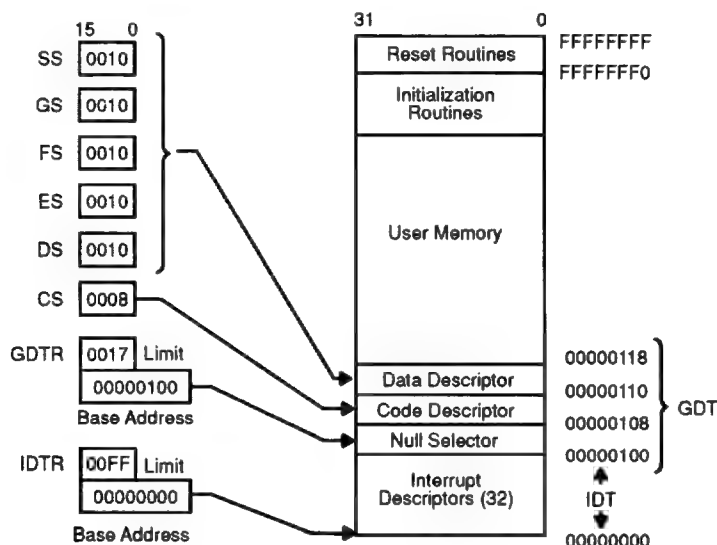
The GDT and IDT registers must refer to a valid GDT and IDT. The IDT should be at least 256 bytes long, and GDT must contain descriptors for the initial code and data segments. Figure 28 shows the tables and Figure 29 shows the descriptors needed for a simple Protected Mode Am386DE microprocessor system. It

has a single code and single data/stack segment each 4 Gbytes long and a single privilege level PL = 0.

The actual method of enabling Protected Mode is to load CR0 with PE bit set, via the MOV CR0, R/M instruction. This puts the Am386DE microprocessor in Protected Mode.

After enabling Protected Mode, the next instruction should execute an intersegment JMP to load the CS register and flush the instruction decode queue. The final step is to load all of the data segment registers with the initial selector values.

An alternate approach to entering Protected Mode that is especially appropriate for multitasking operating systems is to use the built-in task-switch to load all of the registers. In this case, the GDT would contain two TSS descriptors in addition to the code and data descriptors needed for the first task. The first JMP instruction in Protected Mode would jump to the TSS causing a task switch and loading all of the registers with the values stored in the TSS. The TR should be initialized to point to a valid TSS descriptor since a task switch saves the state of the current task in a task state segment.



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Figure 28. Simple Protected System

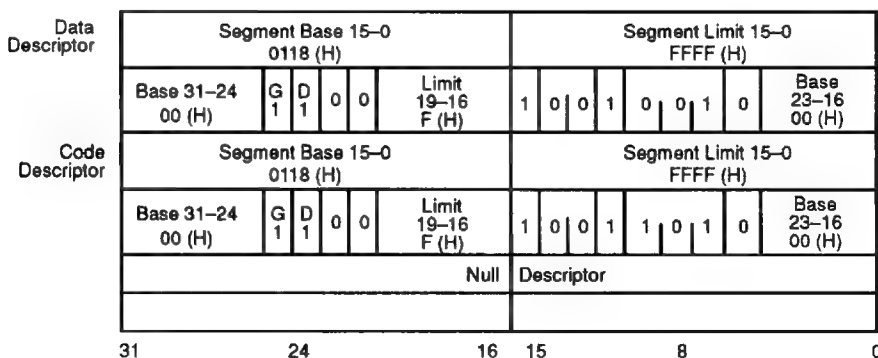


Figure 29. GDT Descriptors for Simple System

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FUNCTIONAL DATA

Introduction

The Am386DE microprocessor features a straight forward functional interface to the external hardware. The Am386DE CPU has separate parallel buses for data and address. The data bus is 32 bits in width and is bidirectional. The address bus outputs 32-bit address values in the most directly usable form for the high-speed local bus: 4 individual Byte Enable signals and the 30 upper-order bits as a binary value. The data and address buses are interpreted and controlled with their associated control signals.

A dynamic data bus sizing feature allows the processor to handle a mix of 32- and 16-bit external buses on a cycle-by-cycle basis (see Dynamic Data Bus Sizing on page 59). If 16-bit bus size is selected, the Am386DE microprocessor automatically makes any adjustment needed, even performing another 16-bit bus cycle to complete the transfer if that is necessary. Any 8-bit peripheral devices may be connected to 32- or 16-bit buses with no loss of performance. A new address pipelining option is provided and applies to 32- and 16-bit buses for substantially improved memory utilization, especially for the most heavily used memory resources.

The address pipelining option, when selected, typically allows a given memory interface to operate with one less wait state than would otherwise be required (see Address Pipelining on page 63). The pipelined bus is also well suited to interleaved memory designs. When address pipelining is requested by the external hardware, the Am386DE microprocessor will output the address and bus cycle definition of the next bus cycle (if it is internally available) even while waiting for the current cycle to be acknowledged.

Non-pipelined address timing, however, is ideal for external cache designs, since the cache memory will typically be fast enough to allow non-pipelined cycles. For maximum design flexibility, the address pipelining option is selectable on a cycle-by-cycle basis.

The processor's bus cycle is the basic mechanism for information transfer, either from system to processor or from processor to system. Am386DE microprocessor bus cycles perform data transfer in a minimum of only two clock periods. On a 32-bit data bus, the maximum Am386DE device transfer, at 33-MHz bandwidth is 66 Mbytes/second. Any bus cycle will be extended for more than two clock periods, however, if external hardware withholds acknowledgment of the cycle. At the appropriate time, acknowledgment is signaled by asserting the Am386DE microprocessor **READY** input.

The Am386DE CPU can relinquish control of its local buses to allow mastership by other devices, such as direct memory access channels. When relinquished, HLDA is the only output pin driven by the Am386DE

microprocessor providing near-complete isolation of the processor from its system. The near-complete isolation characteristic is ideal when driving the system from test equipment and in fault-tolerant applications.

Functional data covered in this section describes the processor's hardware interface. First, the set of signals available at the processor pins is described (see Signal Description on page 63). Following that are the signal waveforms occurring during bus cycles (see Bus Transfer Mechanism on page 58, Bus Functional Description on page 61, and Other Functional Descriptions on page 78).

Signal Description

Introduction

Ahead is a brief description of the Am386DE CPU input and output signals arranged by functional groups (see Figure 30).

Example signal:

M/\overline{IO} —High voltage indicates Memory selected
—Low voltage indicates I/O selected

The signal descriptions sometimes refer to AC timing parameters, such as t25 RESET Setup Time and t26 RESET Hold Time.

Clock (CLK2)

CLK2 provides the fundamental timing for the Am386DE microprocessor. It is divided by 2 internally to generate the internal processor clock used for instruction execution. The internal clock is comprised of two phases, phase one and phase two. Each CLK2 period is a phase of the internal clock. Figure 31 illustrates the relationship. If desired, the phase of the internal processor clock can be synchronized to a known phase by ensuring the RESET signal falling edge meets its applicable setup and hold times, t25 and t26.

Data Bus (D31–D0)

These three-state, bidirectional signals provide the general purpose data path between the Am386DE microprocessor and other devices. Data bus inputs and outputs indicate 1 when High. The data bus can transfer data on 32- and 16-bit buses using a data bus sizing feature controlled by the **BS16** input. See the Bus Control section on page 54. Data bus reads require that read data setup and hold times, t21 and t22, be met for correct operation. In addition, the Am386DE microprocessor requires that all data bus pins be at a valid logic state (High or Low) at the end of each read cycle, when **READY** is asserted. During any write operation (and during halt cycles and shut down cycles), the Am386DE microprocessor always drives all 32 signals of the data bus even if the current bus size is 16 bits.

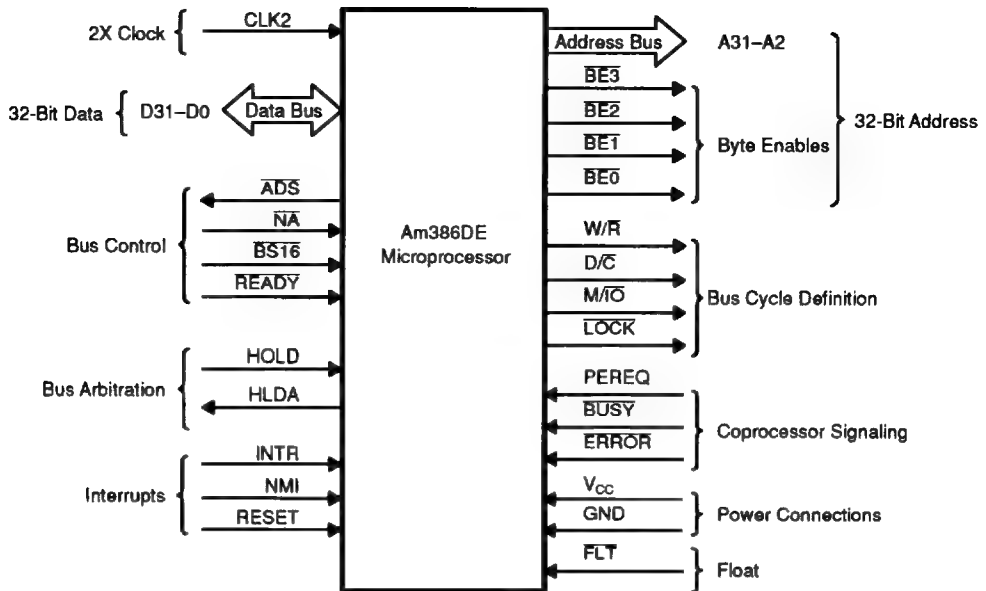


Figure 30. Functional Signal Groups

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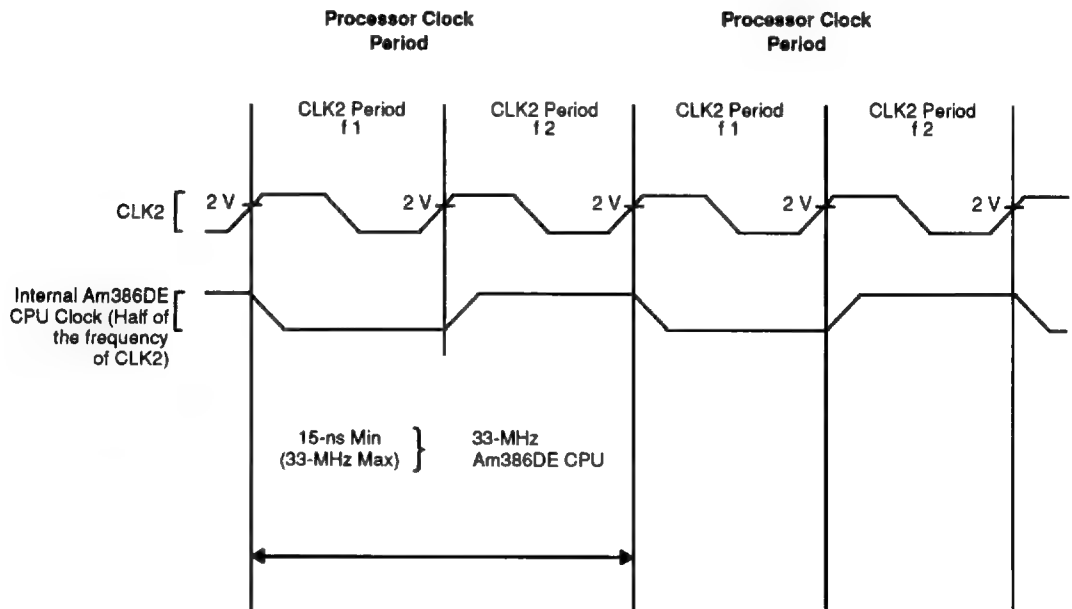


Figure 31. CLK2 Signal and Internal Processor Clock

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Address Bus ($\overline{BE3}$ – $\overline{BE0}$, A31–A2)

These three-state outputs provide physical memory addresses or I/O port addresses. The address bus is capable of addressing 4 Gbytes of physical memory space (00000000H–FFFFFFFH), and 64 Kbytes of I/O address space (00000000H–0000FFFFH) for programmed I/O. I/O transfers automatically generated for Am386DE microprocessor-to-coprocessor communication use I/O addresses 800000F8H–800000FFH, so A31 is High in conjunction with $\overline{M/\overline{IO}}$ Low allows simple generation of the coprocessor select signal.

The Byte Enable outputs, $\overline{BE3}$ – $\overline{BE0}$, directly indicate which bytes of the 32-bit data bus are involved with the current transfer. This is most convenient for external hardware.

$\overline{BE0}$ applies to D7–D0

$\overline{BE1}$ applies to D15–D8

$\overline{BE2}$ applies to D23–D16

$\overline{BE3}$ applies to D31–D24

The number of Byte Enables asserted indicates the physical size of the operand being transferred (1, 2, 3, or 4 bytes). Refer to the Operand Alignment section on page 61.

When a memory write cycle or I/O write cycle is in progress and the operand being transferred occupies only the upper 16 bits of the data bus (D31–D16), duplicate data is simultaneously presented on the corresponding lower 16 bits of the data bus (D15–D0). This duplication is performed for optimum write performance on 16 bit buses. The pattern of write data duplication is a function of the Byte Enables asserted during the write cycle. Table 15 lists the write data present on D31–D0, as a function of the asserted Byte Enable outputs $\overline{BE3}$ – $\overline{BE0}$.

Bus Cycle Definition Signals ($\overline{W/\overline{R}}$, $\overline{D/\overline{C}}$, $\overline{M/\overline{IO}}$, \overline{LOCK})

These three-state outputs define the type of bus cycle being performed. $\overline{W/\overline{R}}$ distinguishes between write and read cycles, $\overline{D/\overline{C}}$ between data and control cycles, $\overline{M/\overline{IO}}$ between memory and I/O cycles, and \overline{LOCK} between locked and unlocked bus cycles.

The primary bus cycle definition signals are $\overline{W/\overline{R}}$, $\overline{D/\overline{C}}$, and $\overline{M/\overline{IO}}$, since these are the signals driven valid as the \overline{ADS} (Address Status output) is driven asserted. The \overline{LOCK} is driven valid at the same time as the first locked bus cycle begins, which due to address pipelining, could be later than \overline{ADS} is driven asserted. See Pipelined Address. The \overline{LOCK} is negated when the \overline{READY} input terminates the last bus cycle that was locked.

Exact bus cycle definitions, as a function of $\overline{W/\overline{R}}$, $\overline{D/\overline{C}}$, and $\overline{M/\overline{IO}}$, are given in Table 16. Note one combination of $\overline{W/\overline{R}}$, $\overline{D/\overline{C}}$, and $\overline{M/\overline{IO}}$ is never given when \overline{ADS} is asserted (however, that combination, which is listed as does not occur, may occur during idle bus states when \overline{ADS} is not asserted). If $\overline{M/\overline{IO}}$, $\overline{D/\overline{C}}$, and $\overline{W/\overline{R}}$ are qualified by \overline{ADS} asserted, then a decoding scheme may be simplified by using this definition.

Bus Control Signals (\overline{ADS} , \overline{READY} , \overline{NA} , $\overline{BS16}$)

Introduction

The following signals allow the processor to indicate when bus cycle has begun and allow other system hardware to control address pipelining, data bus width, and bus cycle termination.

Address Status (\overline{ADS})

This three-state output indicates that a valid bus cycle definition and address ($\overline{W/\overline{R}}$, $\overline{D/\overline{C}}$, $\overline{M/\overline{IO}}$, $\overline{BE3}$ – $\overline{BE0}$, and A31–A2) is being driven at the Am386DE

Table 15. Write Data Duplication as a Function of $\overline{BE3}$ – $\overline{BE0}$

Am386DE CPU Byte Enables				Am386DE CPU Write Data				Automatic Duplication?
$\overline{BE3}$	$\overline{BE2}$	$\overline{BE1}$	$\overline{BE0}$	D31–D24	D23–D16	D15–D8	D7–D0	
High	High	High	Low	Undef	Undef	Undef	A	No
High	High	Low	High	Undef	Undef	B	Undef	No
High	Low	High	High	Undef	C	Undef	C	Yes
Low	High	High	High	D	Undef	D	Undef	Yes
High	High	Low	Low	Undef	Undef	B	A	No
High	Low	Low	High	Undef	C	B	Undef	No
Low	Low	High	High	D	C	D	C	Yes
High	Low	Low	Low	Undef	C	B	A	No
Low	Low	Low	High	D	C	B	Undef	No
Low	Low	Low	Low	D	C	B	A	No

Key: D = Logical Write Data D31–D24 B = Logical Write Data D15–D8
C = Logical Write Data D23–D16 A = Logical Write Data D7–D0

Table 16. Bus Cycle Definition

M/I \bar{O}	D/ \bar{C}	W/ \bar{R}	Bus Cycle Type	Locked?
Low	Low	Low	Interrupt Acknowledge	Yes
Low	Low	High	Does Not Occur	—
Low	High	Low	I/O Data Read	No
Low	High	High	I/O Data Write	No
High	Low	Low	Memory Code Read	No
High	Low	High	Halt: Address = 2 Shutdown: Address = 0 BE $\bar{0}$ High BE $\bar{0}$ Low BE $\bar{1}$ High BE $\bar{1}$ High BE $\bar{2}$ Low BE $\bar{2}$ High BE $\bar{3}$ High BE $\bar{3}$ High A31–A2 Low A31–A2 Low	No
High	High	Low	Memory Data Read	Some Cycles
High	High	High	Memory Data Write	Some Cycles

microprocessor pins. It is asserted during T1 and T2P bus states (see Non-Pipelined Address on page 66 and Pipelined Address on page 70 for additional information on bus states).

Transfer Acknowledge (\overline{READY})

This input indicates the current bus cycle is complete, and the active bytes indicated by BE $\bar{3}$ –BE $\bar{0}$ and BS16 are accepted or provided. When \overline{READY} is sampled asserted during a read cycle or interrupt acknowledge cycle, the Am386DE microprocessor latches the input data and terminates the cycle. When \overline{READY} is sampled asserted during a write cycle, the processor terminates the bus cycle.

\overline{READY} is ignored on the first bus state of all bus cycles, and sampled each bus state thereafter until asserted. \overline{READY} must eventually be asserted to acknowledge every bus cycle, including Halt Indication and Shutdown Indication bus cycles. When being sampled, \overline{READY} must always meet setup and hold times, t19 and t20, for correct operation. See all sections of Bus Functional Description starting on page 61.

Next Address Request (\overline{NA})

This is used to request address pipelining. This input indicates the system is prepared to accept new values of BE $\bar{3}$ –BE $\bar{0}$, A31–A2, W/ \bar{R} , D/ \bar{C} , and M/I \bar{O} from the Am386DE microprocessor even if the end of the current cycle is not being acknowledged on \overline{READY} . If this input is asserted when sampled, the next address is driven onto the bus provided the next bus request is already pending internally. See Address Pipelining on page 63 and Read and Write Cycles on page 65. \overline{NA} must always meet setup and hold times, t15 and t16, for correct operation.

Bus Size 16 ($\overline{BS16}$)

The BS16 feature allows the Am386DE microprocessor to directly connect to 32- and 16-bit data buses. Asserting this input constrains the current bus cycle to use only the lower-order half (D15–D0) of the data bus, corresponding to BE $\bar{0}$ and BE $\bar{1}$. Asserting BS16 has no additional effect if only BE $\bar{0}$ and/or BE $\bar{1}$ are asserted in the current cycle. However, during bus cycles asserting BE $\bar{2}$ or BE $\bar{3}$, asserting BS16 will automatically cause the Am386DE microprocessor to make adjustments for correct transfer of the upper byte(s) using only physical data signals D15–D0.

If the operand spans both halves of the data bus and BS16 is asserted, the Am386DE microprocessor will automatically perform another 16-bit bus cycle. BS16 must always meet setup and hold times, t17 and t18, for correct operation.

Am386DE CPU I/O cycles are automatically generated for coprocessor communication. Since the Am386DE microprocessor must transfer 32-bit quantities between itself and a 387DX math coprocessor, BS16 must not be asserted during 387DX math coprocessor communication cycles.

Bus Arbitration Signals (HOLD, HLDA)

Introduction

This section describes the mechanism by which the processor relinquishes control of its local buses when requested by another bus master device. See Entering and Exiting Hold Acknowledge on page 78 for additional information.

Bus Hold Request (HOLD)

This input indicates some device other than the Am386DE CPU requires bus mastership.

HOLD must remain asserted as long as any other device is a local bus master. HOLD is not recognized while RESET is asserted. If RESET is asserted while HOLD is asserted, RESET has priority and places the bus into an idle state, rather than the hold acknowledge (high impedance) state. HOLD is level-sensitive and is a synchronous input. HOLD signals must always meet setup and hold times, t23 and t24, for correct operation.

Bus Hold Acknowledge (HLDA)

Assertion of this output indicates the Am386DE microprocessor has relinquished control of its local bus in response to HOLD asserted, and is in the Bus Hold Acknowledge state.

The Hold Acknowledge state offers near-complete signal isolation. In the Hold Acknowledge state, HLDA is the only signal being driven by the Am386DE microprocessor. The other output signals or bidirectional signals (D31–D0, BE3–BE0, A31–A2, W/R, D/C, M/I/O, LOCK, and ADS) are in a high-impedance state so the requesting bus master may control them. Pull-up resistors may be desired on several signals to avoid spurious activity when no bus master is driving them. See Resistor Recommendations. Also, one rising edge occurring on the NMI input during Hold Acknowledge is remembered for processing after the HOLD input is negated.

In addition to the normal usage of Hold Acknowledge with DMA controllers or master peripherals, the near-complete isolation has particular attractiveness during system test when test equipment drives the system and in hardware-fault-tolerant applications.

Coprocessor Interface Signals (PEREQ, BUSY, ERROR)

Introduction

In the following sections are descriptions of signals dedicated to the coprocessor interface. In addition to the data bus, address bus, and bus cycle definition signals, these following signals control communication between the Am386DE microprocessor and its 387DX math coprocessor extension.

Coprocessor Request (PEREQ)

When asserted, this input signal indicates a coprocessor request for a data operand to be transferred to/from memory by the Am386DE microprocessor. In response, the Am386DE CPU transfers information between the coprocessor and memory. Because Am386DE microprocessor has internally stored the coprocessor opcode being executed, it performs the requested data transfer with the correct direction and memory address.

PEREQ is level-sensitive and is allowed to be asynchronous to the CLK2 signal.

Coprocessor Busy (BUSY)

When asserted, this input indicates the coprocessor is still executing an instruction and is not yet able to accept

another. When the Am386DE microprocessor encounters any coprocessor instruction that operates on the numeric stack (e.g., load, pop, or arithmetic operation) or the WAIT instruction, this input is first automatically sampled until it is seen to be negated. This sampling of the BUSY input prevents overrunning the execution of a previous coprocessor instruction.

The FNINIT and FNCLEX coprocessor instructions are allowed to execute even if BUSY is asserted, since these instructions are used for coprocessor initialization and exception-clearing.

BUSY is level-sensitive and is allowed to be asynchronous to the CLK2 signal.

BUSY serves an additional function. If BUSY is sampled Low at the falling edge of RESET, the Am386DE microprocessor performs an internal self-test (see the Bus Activity During and Following Reset section on page 84). If BUSY is sampled High, no self-test is performed.

Coprocessor Error (ERROR)

This input signal indicates that the previous coprocessor instruction generated a coprocessor error of a type not masked by the coprocessor's control register. This input is automatically sampled by the Am386DE microprocessor when a coprocessor instruction is encountered, and if asserted, the Am386DE device generates Exception 16 to access the error-handling software.

Several coprocessor instructions, generally those that clear the numeric error flags in the coprocessor or save coprocessor state, do execute without the Am386DE microprocessor generating Exception 16 even if ERROR is asserted. These instructions are FNINIT, FNCLEX, FSTSW, FSTSWAX, FSTCW, FSTENV, FSAVE, FESTENV, and FESAVE.

ERROR is level-sensitive and is allowed to be asynchronous to the CLK2 signal.

Interrupt Signals (INTR, NMI, RESET)

Introduction

The following descriptions cover inputs that can interrupt or suspend execution of the processor's current instruction stream.

Maskable Interrupt Request (INTR)

When asserted, this input indicates a request for interrupt service, which can be masked by the Am386DE CPU Flag Register IF bit. When the Am386DE microprocessor responds to the INTR input, it performs two interrupt acknowledge bus cycles, and at the end of the second, latches an 8-bit interrupt vector on D17–D0 to identify the source of the interrupt.

INTR is level-sensitive and is allowed to be asynchronous to the CLK2 signal. To assure recognition of an

INTR request, INTR should remain asserted until the first interrupt acknowledge bus cycle begins.

Non-Maskable Interrupt Request (NMI)

This input indicates a request for interrupt service, which cannot be masked by software. The non-maskable interrupt request is always processed according to the pointer or gate in slot 2 of the interrupt table. Because of the fixed NMI slot assignment, no interrupt acknowledge cycles are performed when processing NMI.

NMI is rising edge-sensitive and is allowed to be asynchronous to the CLK2 signal. To assure recognition of NMI, it must be negated for at least eight CLK2 periods, and then be asserted for at least eight CLK2 periods.

Once NMI processing has begun, no additional NMI's are processed until after the next IRET instruction, which is typically the end of the NMI service routine. If NMI is re-asserted prior to that time, however, one rising edge on NMI will be remembered for processing after executing the next IRET instruction.

Reset (RESET)

This input signal suspends any operation in progress and places the Am386DE microprocessor in a known reset state. The Am386DE device is reset by asserting RESET for 15 or more CLK2 periods (80 or more CLK2 periods before requesting self-test). When RESET is asserted, all other input pins, except \overline{FLT} , are ignored,

and all other bus pins are driven to an idle bus state as shown in Table 17. If RESET and HOLD are both asserted at a point in time, RESET takes priority even if the Am386DE device was in a Hold Acknowledge state prior to RESET asserted.

Table 17. Pin State (Idle Bus) During Reset

Pin Name	Signal Level During Reset
ADS	High
D31-D0	High Impedance
BE3-BE0	Low
A31-A2	High
W/ \overline{R}	Low
D/ \overline{C}	High
M/ \overline{IO}	Low
\overline{LOCK}	High
HLDA	Low

RESET is level-sensitive and must be synchronous to the CLK2 signal. If desired, the phase of the internal processor clock and the entire Am386DE CPU state can be completely synchronized to external circuitry by ensuring the RESET signal falling edge meets its applicable setup and hold times, t25 and t26. The signal summary is shown in Table 18.

Table 18. Am386DE Microprocessor Signal Summary

Signal Name	Function	Active State	Input/Output	Input Synchron or Asynch to CLK2	Output High Impedance During HLDA?
CLK2	Clock	—	I	—	—
D31-D0	Data Bus	High	I/O	S	Yes
BE3-BE0	Byte Enables	Low	O	—	Yes
A31-A2	Address Bus	High	O	—	Yes
W/ \overline{R}	Write-Read Indication	High	O	—	Yes
D/ \overline{C}	Data-Control Indication	High	O	—	Yes
M/ \overline{IO}	Memory-I/O Indication	High	O	—	Yes
\overline{LOCK}	Bus Lock Indication	Low	O	—	Yes
ADS	Address Status	Low	O	—	Yes
NA	Next Address Request	Low	I	S	—
BS16	Bus Size 16	Low	I	S	—
READY	Transfer Acknowledge	Low	I	S	—
HOLD	Bus Hold Request	High	I	S	—
HLDA	Bus Hold Acknowledge	High	O	—	No
PEREQ	Coprocessor Request	High	I	A	—
BUSY	Coprocessor Busy	Low	I	A	—
ERROR	Coprocessor Error	Low	I	A	—
INTR	Maskable Interrupt Request	High	I	A	—
NMI	Non-Maskable Intrpt Request	High	I	A	—
RESET	Reset	High	I	S	—

Bus Transfer Mechanism

Introduction

All data transfers occur as a result of one or more bus cycles. Logical data operands of byte, word, and Dword lengths may be transferred without restrictions on physical address alignment. Any byte boundary may be used, although two or even three physical bus cycles are performed as required for unaligned operand transfers. See Dynamic Data Bus Sizing on page 59 and Operand Alignment on page 61.

The Am386DE microprocessor address signals are designed to simplify external system hardware. Higher-order address bits are provided by A31–A2. Lower-order address in the form of BE3–BE0 directly provides linear selects for the four bytes of the 32-bit data bus. Physical operand size information is thereby implicitly provided for each bus cycle in the most usable form.

Byte Enable outputs, BE3–BE0, are asserted when their associated data bus bytes are involved with the present bus cycle, as listed in Table 19. During a bus cycle, any possible pattern of contiguous asserted Byte Enable outputs can occur, but never patterns having a negated Byte Enable separating two or three asserted Enables.

Table 19. Byte Enables and Associated Data and Operand Bytes

Byte Enable Signal	Associated Data Bus Signals
BE0	D7–D0 (Byte 0—least significant)
BE1	D15–D8 (Byte 1)
BE2	D23–D16 (Byte 2)
BE3	D31–D24 (Byte 3—most significant)

Address bits A0 and A1 of the physical operand's base address can be created when necessary (for instance, for MULTIBUS I or MULTIBUS II interface), as a function of the lowest-order asserted Byte Enable. This is shown by Table 20. Logic to generate A0 and A1 is given by Figure 32.

Each bus cycle is composed of at least two bus states and each bus state requires one processor clock period. Additional bus states added to a single bus cycle are called wait states. See Bus Functional Description section starting on page 61.

Since a bus cycle requires a minimum of two bus states (equal to two processor clock periods), data can be transferred between external devices and the Am386DE CPU at a maximum rate of one 4-byte Dword every two processor clock periods, for a maximum bus bandwidth of 66 Mbytes/sec (Am386DE microprocessor operating at 33-MHz processor clock rate).

Memory and I/O Spaces

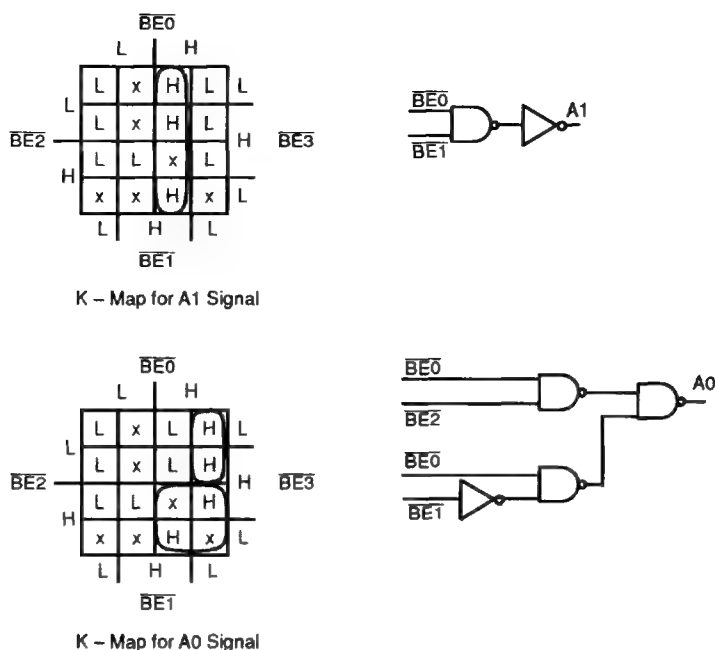
Bus cycles may access physical memory space or I/O space. Peripheral devices in the system may be either memory-mapped, or I/O-mapped, or both. As shown in Figure 33, physical memory addresses range from 00000000H to FFFFFFFFH (4 Gbytes) and I/O addresses from 00000000H to 0000FFFFH (64 Kbytes) for programmed I/O. Note the I/O addresses used by the automatic I/O cycles for coprocessor communication are 800000F8H to 800000FFH, beyond the address range of programmed I/O, to allow easy generation of a coprocessor chip select signal using the A31 and M/I0 signals.

Memory and I/O Organization

The Am386DE microprocessor datapath to memory and I/O spaces can be 32- or 16-bits wide. When 32-bits wide, memory and I/O spaces are organized naturally as arrays of physical 32-bit Dwords. Each memory or I/O Dword has four individually addressable bytes at

Table 20. Generating A31–A0 from BE3–BE0 and A31–A2

Am386DE CPU Address Signals								
A31	A2				BE3	BE2	BE1	BE0
	Physical Base Address							
A31	A2	A1	A0				
A31	A2	0	0	X	X	X	Low
A31	A2	0	1	X	X	Low	High
A31	A2	1	0	X	Low	High	High
A31	A2	1	1	Low	High	High	High

Figure 32. Logic to Generate A0, A1 from $\overline{\text{BE}}_3$ – $\overline{\text{BE}}_0$

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consecutive byte addresses. The lowest-addressed byte is associated with data signals D17–D0; the highest-addressed byte with D31–D24.

The Am386DE microprocessor includes a bus control input, $\overline{\text{BS}}_{16}$, that also allows direct connection to 16-bit memory or I/O spaces organized as a sequence of 16-bit word. Cycles to 32- and 16-bit memory or I/O devices may occur in any sequence, since the $\overline{\text{BS}}_{16}$ control is sampled during each bus cycle. (See Dynamic Data Bus Sizing.) The Byte Enable signals, $\overline{\text{BE}}_3$ – $\overline{\text{BE}}_0$, allow byte granularity when addressing any memory or I/O structure, whether 32- or 16-bits wide.

Dynamic Data Bus Sizing

Dynamic Data Bus Sizing is a feature allowing direct processor connection to 32- or 16-bit data buses for memory or I/O. A single processor may connect to both size buses. Transfers to or from 32- or 16-bit ports are supported by dynamically determining the bus width during each bus cycle. During each bus cycle an address decoding circuit or the slave device itself may assert $\overline{\text{BS}}_{16}$ for 16-bit ports, or negate $\overline{\text{BS}}_{16}$ for 32-bit ports.

With $\overline{\text{BS}}_{16}$ asserted, the processor automatically converts operand transfers larger than 16 bits, or misaligned 16-bit transfers, into two or three transfers as required. All operand transfers physically occur on D15–D0 when $\overline{\text{BS}}_{16}$ is asserted. Therefore, 16-bit

memories or I/O devices only connect on data signals D15–D0. No extra transceivers are required.

Asserting $\overline{\text{BS}}_{16}$ only affects the processor when $\overline{\text{BE}}_2$ and/or $\overline{\text{BE}}_3$ are asserted during the current cycle. If only D15–D0 are involved with the transfer, asserting $\overline{\text{BS}}_{16}$ has no effect since the transfer can proceed normally over a 16-bit bus whether $\overline{\text{BS}}_{16}$ is asserted or not. In other words, asserting $\overline{\text{BS}}_{16}$ has no effect when only the lower half of the bus is involved with the current cycle.

There are two types of situations where the processor is affected by asserting $\overline{\text{BS}}_{16}$, depending on which Byte Enables are asserted during the current bus cycle.

Upper Half Only:

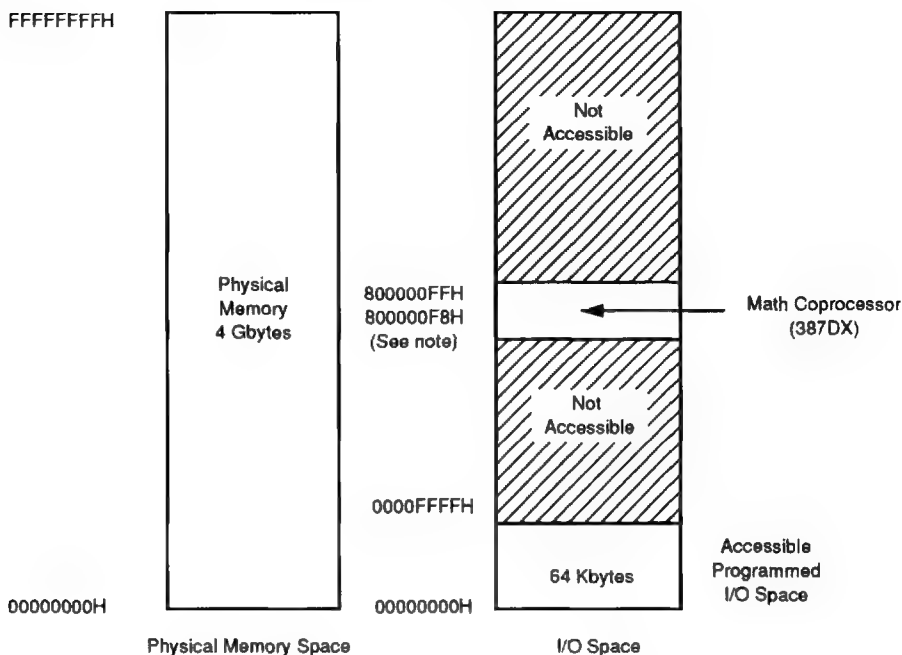
Only $\overline{\text{BE}}_2$ and/or $\overline{\text{BE}}_3$ asserted.

Upper and Lower Half:

At least $\overline{\text{BE}}_1$, $\overline{\text{BE}}_2$ asserted (and perhaps also $\overline{\text{BE}}_0$ and/or $\overline{\text{BE}}_3$).

Effect of asserting $\overline{\text{BS}}_{16}$ during Upper Half Only read cycles:

Asserting $\overline{\text{BS}}_{16}$ during Upper Half Only reads causes the Am386DE microprocessor to read data on the lower 16 bits of the data bus and ignore data on the upper 16 bits of the data bus. Data that would have been read from D31–D16 (as indicated by $\overline{\text{BE}}_2$ and $\overline{\text{BE}}_3$) will instead be read from D15–D0, respectively.



Note:

Since A31 is High during automatic communication with coprocessor, A31 High and $\overline{M\overline{A}O}$ Low can be used to easily generate a coprocessor select signal.

Figure 33. Physical Memory and I/O Spaces

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Effect of asserting $\overline{BS16}$ during Upper Half Only write cycles:

Asserting $\overline{BS16}$ during Upper Half Only writes does not affect the Am386DE microprocessor. When only $\overline{BE2}$ and/or $\overline{BE3}$ are asserted during a Write cycle, the Am386DE microprocessor always duplicates data signals D31-D16 onto D15-D0 (see Table 15). Therefore, no further Am386DE CPU action is required to perform these writes on 32- or 16-bit buses.

Effect of asserting $\overline{BS16}$ during Upper and Lower Half read cycles:

Asserting $\overline{BS16}$ during Upper and Lower Half reads causes the processor to perform two 16-bit read cycles for complete physical operand transfer. Bytes 0 and 1 (as indicated by $\overline{BE0}$ and $\overline{BE1}$) are read on the first cycle using D15-D0. Bytes 2 and 3 (as indicated by $\overline{BE2}$ and $\overline{BE3}$) are read during the second cycle, again using D15-D0. D31-D16 are ignored during both 16-bit cycles. $\overline{BE0}$ and $\overline{BE1}$ are always negated during the second 16-bit cycle. See Figure 43 Cycles 2 and 2A.

Effect of asserting $\overline{BS16}$ during Upper and Lower Half write cycles:

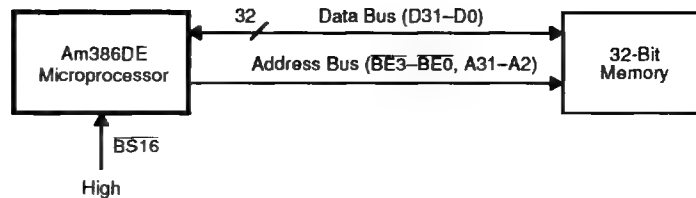
Asserting $\overline{BS16}$ during Upper and Lower Half writes causes the Am386DE microprocessor to perform two

16-bit write cycles for complete physical operand transfer. All bytes are available the first write cycle allowing external hardware to receive Bytes 0 and 1 (as indicated by $\overline{BE0}$ and $\overline{BE1}$) using D15-D0. On the second cycle the Am386DE microprocessor duplicates Bytes 2 and 3 on D15-D0 and Bytes 2 and 3 (as indicated by $\overline{BE2}$ and $\overline{BE3}$) are written using D15-D0. $\overline{BE0}$ and $\overline{BE1}$ are always negated during the second 16-bit cycle. $\overline{BS16}$ must be asserted during the second 16-bit cycle. See Figure 43 Cycles 1 and 1A.

Interfacing with 32- and 16-Bit Memories

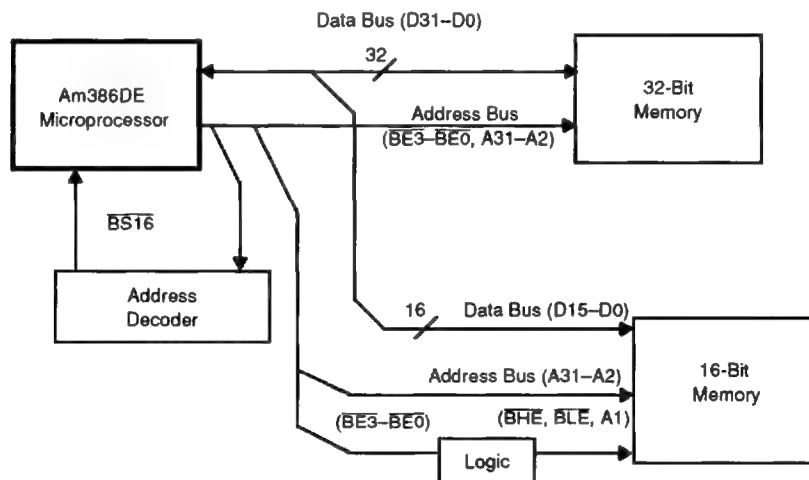
In 32-bit-wide physical memories such as Figure 34, each physical Dword begins at a byte address that is a multiple of 4. A31-A2 are directly used as a Dword selects and $\overline{BE3}$ - $\overline{BE0}$ as byte selects. $\overline{BS16}$ is negated for all bus cycles involving the 32-bit array.

When 16-bit-wide physical arrays are included in the system, as in Figure 35, each 16-bit physical word begins at an address that is a multiple of 2. Note the address is decoded to assert $\overline{BS16}$ only during bus cycles involving the 16-bit array. If desiring to use pipelined address with 16-bit memories, then $\overline{BE3}$ - $\overline{BE0}$ and $\overline{W/R}$ are also decoded to determine when $\overline{BS16}$ should be asserted. (See Pipelined Address with Dynamic Data Bus Sizing on page 77.)



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Figure 34. Am386DE Microprocessor with 32-Bit Memory



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Figure 35. Am386DE Microprocessor with 32-Bit and 16-Bit Memory

A31-A2 are directly usable for addressing 32- and 16-bit devices. To address 16-bit devices, A1 and two Byte Enable signals are also needed.

To generate an A1 signal and two Byte Enable signals for 16-bit access, $\overline{BE3}$ – $\overline{BE0}$ should be decoded as in Table 21. Note that certain combinations of $\overline{BE3}$ – $\overline{BE0}$ are never generated by the Am386DE microprocessor, leading to “don’t care” conditions in the decoder. Any $\overline{BE3}$ – $\overline{BE0}$ decoder, such as shown in Figure 36, may use the non-occurring $\overline{BE3}$ – $\overline{BE0}$ combinations to its best advantage.

Operand Alignment

With the flexibility of memory addressing on the Am386DE microprocessor, it is possible to transfer a logical operand that spans more than one physical Dword or Word of memory or I/O. Examples are 32-bit Dword operands beginning at addresses not evenly

divisible by a 4- or a 16-bit Word operand split between two physical Dwords of memory array.

Operand alignment and data bus size dictates when multiple bus cycles are required. Table 22 describes the transfer cycles generated for all combinations of logical operand lengths, alignment, and data bus sizing. When multiple bus cycles are required to transfer a multi-byte logical operand, the highest-order bytes are transferred first (but if $\overline{BS16}$ asserted requires two 16-bit cycles be performed, that part of the transfer is lowest-order first).

Bus Functional Description

Introduction

The Am386DE microprocessor has separate, parallel buses for data and address. The data bus is 32 bits in width and is bidirectional. The address bus provides a 32-bit value using 30 signals for the 30 upper-order address bits and 4 Byte Enable signals to directly

Table 21. Generating A1, BHE, and BLE for Addressing 16-Bit Devices

Am386DE CPU Signals				16-Bit Bus Signals			Comments
BE3	BE2	BE1	BE0	A1	BHE	BLE (A0)	
H*	H*	H*	H*	X	X	X	X—no active bytes
H	H	H	L	L	H	L	
H	H	L	H	L	L	H	
H	H	L	L	L	L	L	
H	L	H	H	H	H	L	X—non-contiguous bytes
H*	L*	H*	L*	X	X	X	
H	L	L	H	L	L	H	
H	L	L	L	L	L	L	
L	H	H	H	H	L	H	X—non-contiguous bytes X—non-contiguous bytes X—non-contiguous bytes
L*	H*	H*	L*	X	X	X	
L*	H*	L*	H*	X	X	X	
L*	H*	L*	L*	X	X	X	
L	L	H	H	H	L	L	X—non-contiguous bytes
L*	L*	H*	L*	X	X	X	
L	L	L	H	L	L	H	
L	L	L	L	L	L	L	

Note:

BLE asserted when D7–D0 of 16-bit bus is active.

BHE asserted when D15–D8 of 16-bit bus is active.

A1 Low for all even words; A1 High for all odd words.

Key: X = "Don't Care"

H = High voltage level

L = Low voltage level

* = A non-occurring pattern of Byte Enables; either none are asserted or the pattern has Byte Enables asserted for non-contiguous bytes.

indicate the active bytes. These buses are interpreted and controlled via several associated definition or control signals.

The definition of each bus cycle is given by three definition signals: M/ \overline{O} , W/ \overline{R} , and D/ \overline{C} . At the same time, a valid address is present on the Byte Enable signals BE3–BE0 and other address signals, A31–A2. A status signal, \overline{ADS} , indicates when the Am386DE CPU issues a new bus cycle definition and address.

Collectively, the address bus, data bus, and all associated control signals are referred to simply as the bus.

When active, the bus performs one of the bus cycles below.

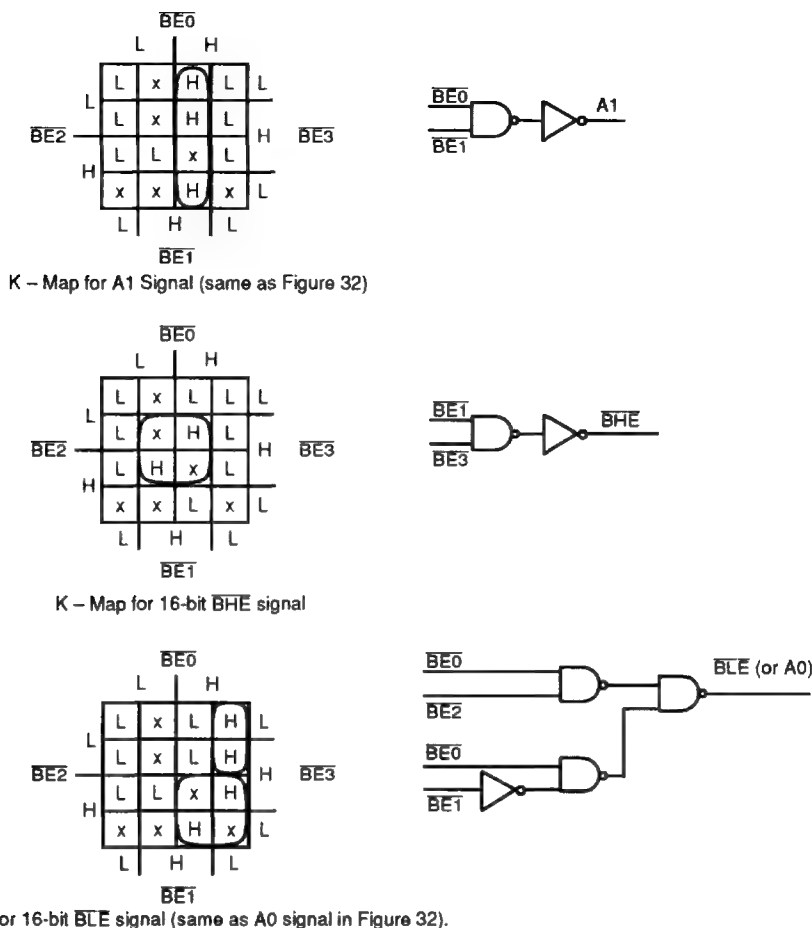
1. Read from memory space.
2. Locked read from memory space.
3. Write to memory space.
4. Locked write to memory space.
5. Read from I/O space (or coprocessor).
6. Write to I/O space (or coprocessor).
7. Interrupt acknowledge.
8. Indicate halt or indicate shutdown.

Table 16 shows the encoding of the bus cycle definition signals for each bus cycle. See the Bus Cycle Definition Signals section on page 54.

The data bus has a dynamic sizing feature supporting 32- and 16-bit bus size. Data bus size is indicated to the Am386DE microprocessor using its Bus Size 16 (BS16) input. All bus functions can be performed with either data bus size.

When the Am386DE CPU bus is not performing one of the activities listed above, it is either Idle or in the Hold Acknowledge state, which may be detected by external circuitry. The Idle state can be identified by the Am386DE microprocessor giving no further assertions on its address strobe output (\overline{ADS}) since the beginning of its most recent bus cycle, and the most recent bus cycle has been terminated. The Hold Acknowledge state is identified by the Am386DE CPU asserting its Hold Acknowledge (HLDA) output.

The shortest time unit of bus activity is a bus state. A bus state is one processor clock period (two CLK2 periods) in duration. A complete data transfer occurs during a bus cycle, composed of two or more bus states.



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Figure 36. Logic to Generate A1, BHE, and BLE for 16-Bit Buses

The fastest Am386DE microprocessor bus cycle requires only two bus states. For example, three consecutive bus read cycles, each consisting of two bus states, are shown by Figure 37. The bus states in each cycle are named T1 and T2. Any memory or I/O address may be accessed by such a two-state bus cycle, if the external hardware is fast enough. The high-bandwidth, two-clock bus cycle realizes the full potential of fast main memory, or cache memory.

Every bus cycle continues until it is acknowledged by the external system hardware, using the Am386DE microprocessor $\overline{\text{READY}}$ input. Acknowledging the bus cycle at the end of the first T2 results in the shortest bus cycle, requiring only T1 and T2. If $\overline{\text{READY}}$ is not immediately asserted, however, T2 states are repeated indefinitely until the $\overline{\text{READY}}$ input is sampled asserted.

Address Pipelining

The address pipelining option provides a choice of bus cycle timings. Pipelined or non-pipelined address timing is selectable on a cycle-by-cycle basis with the Next Address (NA) input.

When address pipelining is not selected, the current address and bus cycle definition remain stable throughout the bus cycle.

When address pipelining is selected, the address (BE3–BE0, A31–A2) and definition (W/ $\overline{\text{R}}$, D/ $\overline{\text{C}}$, and M/ $\overline{\text{I}}$ O) of the next cycle are available before the end of the current cycle. To signal their availability, the Am386DE microprocessor address status output (ADS) is also asserted. Figure 38 illustrates the fastest read cycles with pipelined address timing.

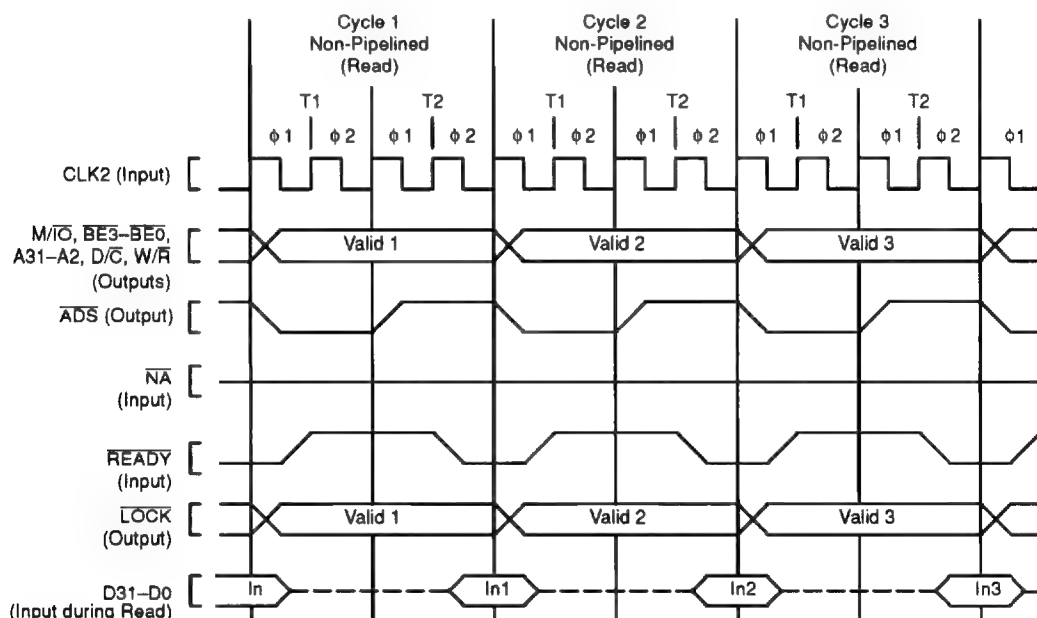
Table 22. Transfer Bus Cycles for Bytes, Words, and Dwords

	Byte-Length of Logical Operand								
	1	2				4			
Physical Byte Address in Memory (low-order bits)	xx	00	01	10	11	00	01	10	11
Transfer Cycles over 32-bit Data Bus	b	w	w	w	hb,* lb	d	hd ld	hw, lw	h3, lb
Transfer Cycles over 16-bit Data Bus	b	w	lb, hb	w	hb, lb	lw, hw	hb, lb	hw, lw	mw, hb, lb
							lb, mw		

Key:

b = Byte transfer
w = Word transfer
l = low-order portion
m = mid-order portion
3 = 3-byte transfer
d = Dword transfer
h = high-order portion
x = Don't care

*For this case, 8086, 8088, 80186, 80188, 80286 transfer lb first, then hb.



Note:

Fastest non-pipelined bus cycles consist of T1 and T2

Figure 37. Fastest Read Cycles with Non-Pipelined Address Timing

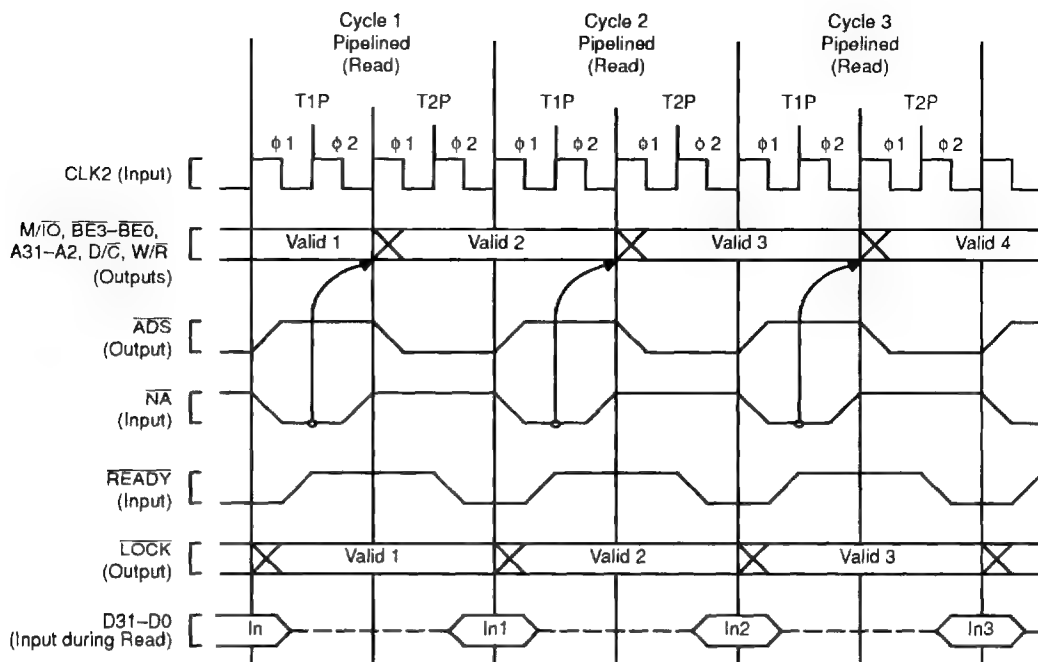
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Note from Figure 38, the fastest bus cycles using pipelined address require only two bus states, named T1P and T2P. Therefore, cycles with pipelined address timing allow the same data bandwidth as non-pipelined cycles, but address-to-data access time is increased compared to that of a non-pipelined cycle.

By increasing the address-to-data access time, pipelined address timing reduces wait state requirements.

For example, if one wait state is required with non-pipelined address timing, no wait states would be required with pipelined address.

Pipelined address timing is useful in typical systems having address latches. In those systems, once an address has been latched, pipelined availability of the next address allows decoding circuitry to generate chip selects (and other necessary select signals) in advance,

**Note:**

Fastest pipelined bus cycles consist of T1P and T2P.

Figure 38. Fastest Read Cycles with Pipelined Address Timing

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so selected devices are accessed immediately when the next cycle begins. In other words, the decode time for the next cycle can be overlapped with the end of the current cycle.

If a system contains a memory structure of two or more interleaved memory banks, pipelined address timing potentially allows even more overlap of activity. This is true when the interleaved memory controller is designed to allow the next memory operation to begin in one memory bank while the current bus cycle is still activating another memory bank. Figure 39 shows the general structure of the Am386DE microprocessor with two-bank and four-bank interleaved memory. Note each memory bank of the interleaved memory has full data bus width (32-bit data width typically, unless 16-bit bus size is selected).

Further details of pipelined address timing are given in Pipelined Address on page 70; Initiating and Maintaining Pipelined Address on page 70; and, Pipelined Address with Dynamic Data Bus Sizing on page 77.

Read and Write Cycles

Introduction

Data transfers occur as a result of bus cycles, classified as Read or Write cycles. During Read cycles, data is

transferred from an external device to the processor. During Write cycles, data is transferred in the other direction, from the processor to an external device.

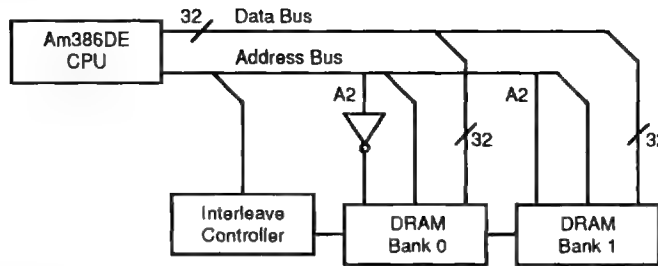
Two choices of address timing are dynamically selectable: non-pipelined or pipelined. After a bus idle state, the processor always uses non-pipelined address timing. However, the \overline{NA} (Next Address) input may be asserted to select pipelined address timing for the next bus cycle. When pipelining is selected and the Am386DE microprocessor has a bus request pending internally, the address and definition of the next cycle is made available even before the current bus cycle is acknowledged by \overline{READY} . Generally, the \overline{NA} input is sampled each bus cycle to select the desired address timing for the next bus cycle.

Two choices of physical data bus width are dynamically selectable: 32 bits or 16 bits. Generally, the $\overline{BS16}$ (Bus Size 16) input is sampled near the end of the bus cycle to confirm the physical data bus size applicable to the current cycle. Negation of $\overline{BS16}$ indicates a 32-bit size and assertion indicates a 16-bit bus size.

If 16-bit bus size is indicated, the Am386DE CPU automatically responds as required to complete the transfer on a 16-bit data bus. Depending on the size and

Two-Bank Interleaved Memory:

- a. Address signal A2 selects bank
- b. 32-bit datapath to each bank



Four-Bank Interleaved Memory:

- a. Address signals A3 and A2 select bank
- b. 32-bit datapath to each bank

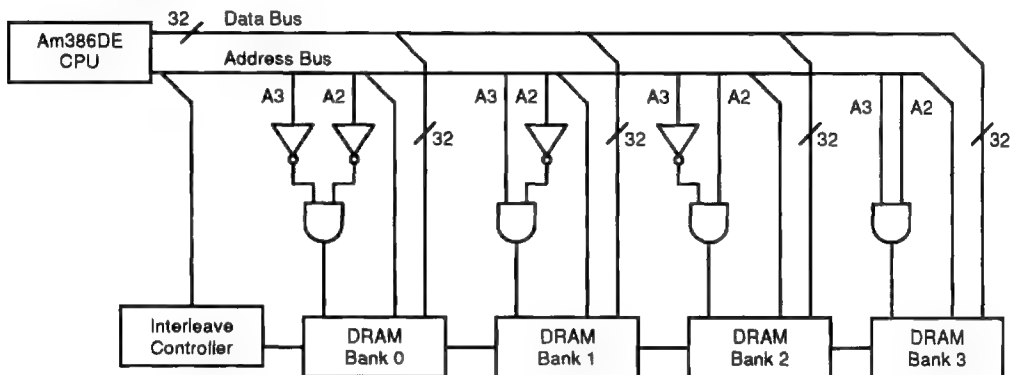


Figure 39. Two-Bank and Four-Bank Interleaved Memory Structure

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alignment of the operand, another 16-bit bus cycle may be required. Table 21 provides all details. When necessary, the Am386DE microprocessor performs an additional 16-bit bus cycle, using D15–D0 in place of D31–D16.

Terminating a Read cycle or Write cycle, like any bus cycle, requires acknowledging the cycle by asserting the **READY** input. Until acknowledged, the processor inserts wait states into the bus cycle to allow adjustment for the speed of any external device. External hardware that has decoded the address and bus cycle type asserts the **READY** input at the appropriate time.

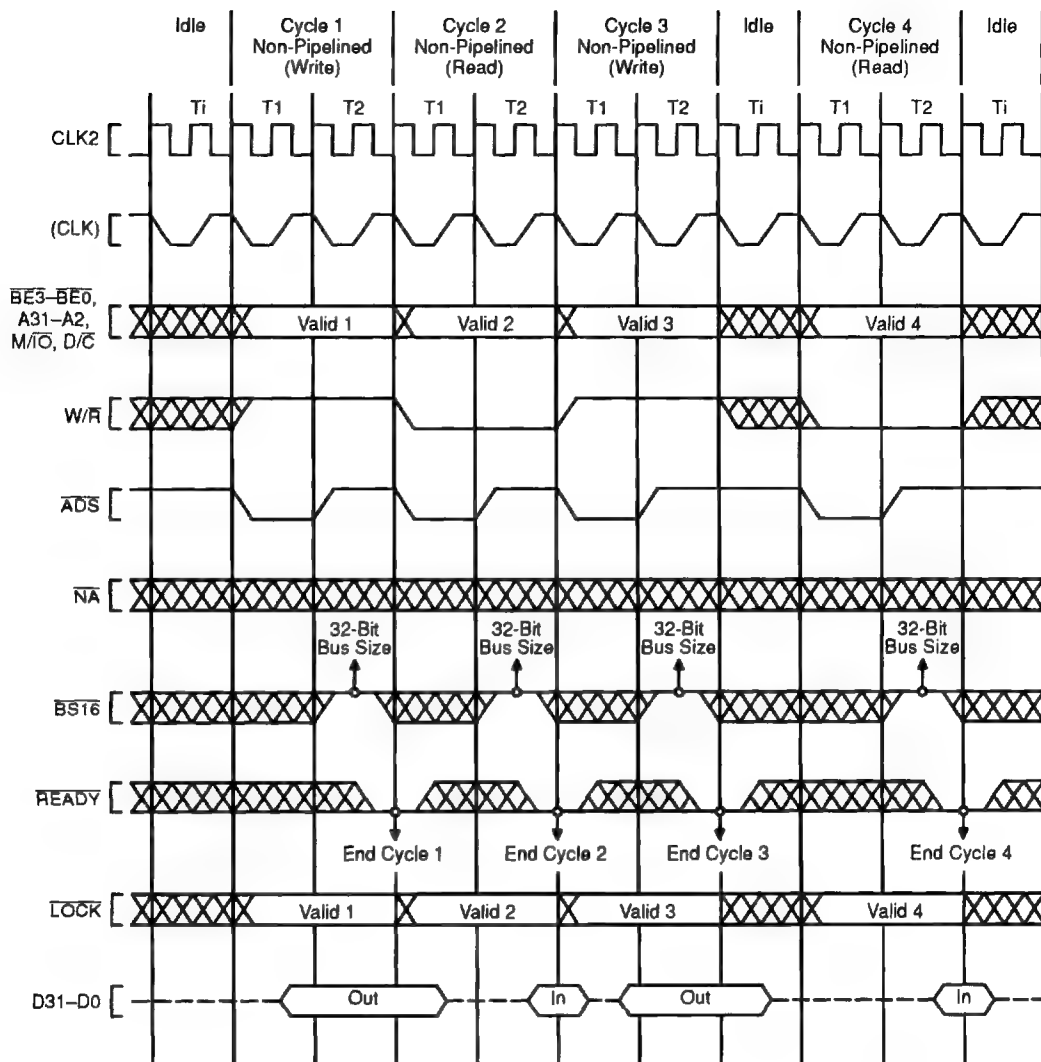
At the end of the second bus state within the bus cycle, $\overline{\text{READY}}$ is sampled. At that time, if external hardware acknowledges the bus cycle by asserting READY , the bus cycle terminates as shown in Figure 40. If $\overline{\text{READY}}$ is negated as in Figure 41, the cycle continues another bus state (a wait state) and $\overline{\text{READY}}$ is sampled again at

the end of that state. This continues indefinitely until the cycle is acknowledged by READY asserted.

When the current cycle is acknowledged, the Am386DE microprocessor terminates it. When a Read cycle is acknowledged, the Am386DE CPU latches the information present at its data pins. When a Write cycle is acknowledged, the Am386DE CPU write data remains valid throughout phase one of the next bus state to provide write data hold time.

Non-Pipelined Address

Any bus cycle may be performed with non-pipelined address timing. For example, Figure 40 shows a mixture of Read and Write cycles with non-pipelined address timing. Figure 40 shows that the fastest possible cycles with non-pipelined address have two bus states per bus cycle. The states are named T1 and T2. In phase one of the T1, the address signals and bus cycle definition signals are driven valid, and to signal their

**Note:**

Idle states are shown here for diagram variety only. Write cycles are not always followed by an idle state. An active bus cycle can immediately follow the write cycle.

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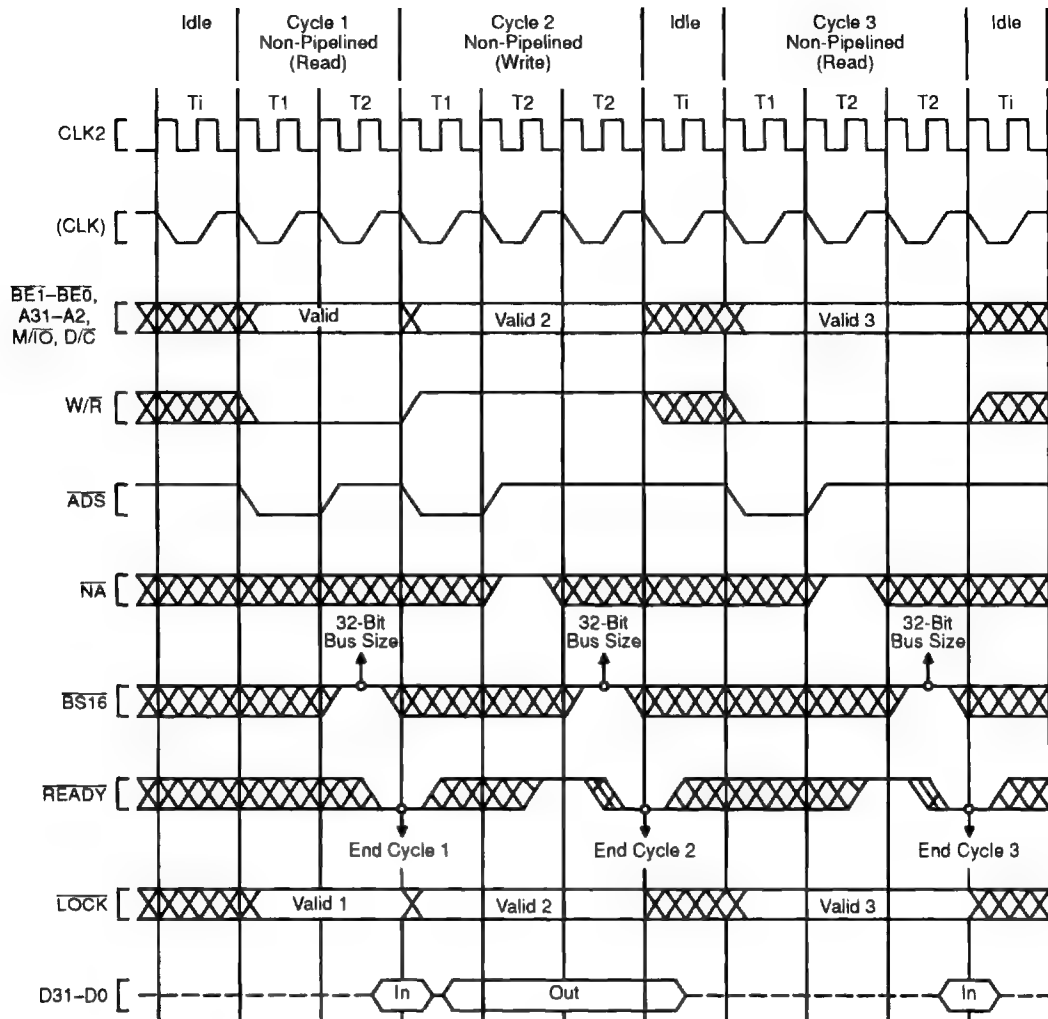
Figure 40. Various Bus Cycles and Idle States with Non-Pipelined Address (Zero Wait States)

availability, address status (\overline{ADS}) is simultaneously asserted.

During Read or Write cycles, the data bus behaves as follows. If the cycle is a read, the Am386DE microprocessor floats its data signals to allow driving by the external device being addressed. The Am386DE device requires that all data bus pins be at a valid logic state (High or Low) at the end of each read cycle, when \overline{READY} is asserted, even if all byte enables are not asserted. The system **must** be designed to meet this

requirement. If the cycle is a write, data signals are driven by the Am386DE device beginning in phase two of T1 until phase one of the bus state following cycle acknowledgment.

Figure 41 illustrates non-pipelined bus cycles with one wait added to Cycles 2 and 3. \overline{READY} is sampled negated at the end of the first T2 in Cycles 2 and 3. Therefore, Cycles 2 and 3 have T2 repeated. At the end of the second T2, \overline{READY} is sampled asserted.



Note:

Idle states are shown here for diagram variety only. Write cycles are not always followed by an idle state. An active bus cycle can immediately follow the write cycle.

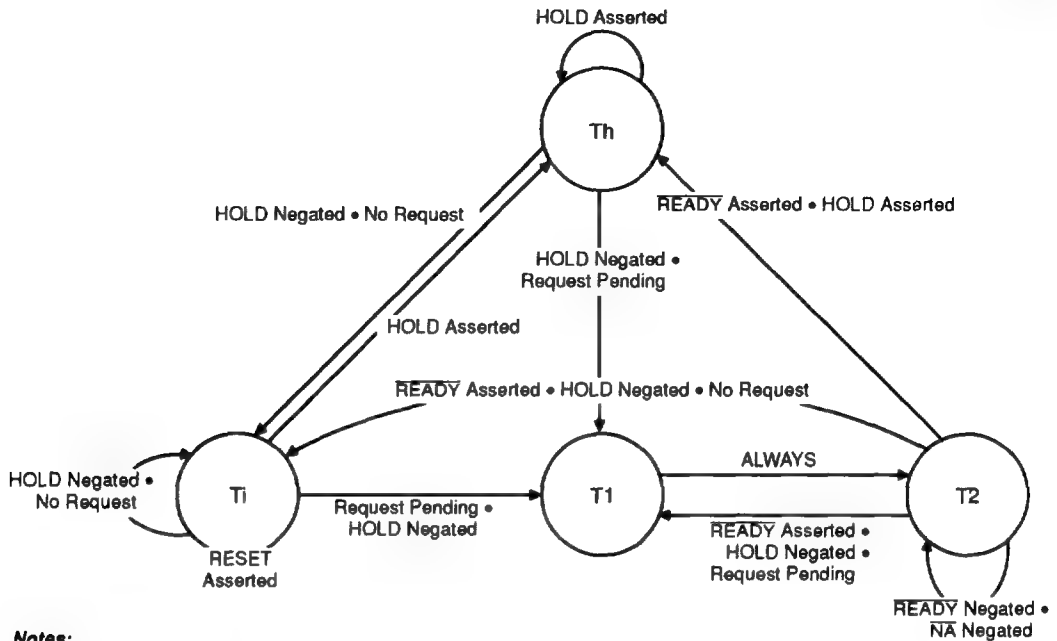
18421A-044

Figure 41. Various Bus Cycles and Idle States with Non-Pipelined Address (Various Number of Wait States)

When address pipelining is not used, the address and bus cycle definition remain valid during all wait states. When wait states are added and you desire to maintain non-pipelined address timing, it is necessary to negate \overline{NA} during each T2 state except the last one, as shown in Figure 41 Cycles 2 and 3. If \overline{NA} is sampled asserted during a T2 other than the last one, the next state would be T2I (for pipelined address) or T2P (for pipelined address) instead of another T2 (for non-pipelined address).

Figure 42 illustrates the bus states and transitions when address pipelining is not used. The bus transitions between four possible states: T1, T2, Ti, and Th. Bus cycles consist of T1 and T2, with T2 being repeated for wait states. Otherwise, the bus may be idle in the Ti state, or in hold acknowledge, the Th state.

When address pipelining is not used, the bus state diagram is as shown in Figure 42. When the bus is idle, it is in state Ti. Bus cycles always begin with T1. T1 always leads to T2. If a bus cycle is not acknowledged during T2 and \overline{NA} is negated, T2 is repeated. When a cycle is

**Notes:****Bus States:**

T1—First clock of a non-pipelined bus cycle (Am386DE microprocessor drives new address and asserts $\overline{\text{ADS}}$).

T2—Subsequent clocks of a bus cycle when $\overline{\text{NA}}$ has not been sampled asserted in the current bus cycle.

Ti—Idle state.

Th—Hold Acknowledge state (Am386DE microprocessor asserts $\overline{\text{HLDA}}$).

The fastest bus cycle consists of two states: T1 and T2.

Four basic bus states describe bus operation when not using pipelined address. These states do include $\overline{\text{BS16}}$ usage for 32-bit and 16-bit bus size. If asserting $\overline{\text{BS16}}$ requires second 16-bit bus cycle to be performed, it is performed before $\overline{\text{HOLD}}$ asserted acknowledged.

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Figure 42. Bus States (Not Using Pipelined Address)

acknowledged during T2, the following state will be T1 of the next bus cycle if a bus request is pending internally, or Ti if there is no bus request pending, or Th if the $\overline{\text{HOLD}}$ input is being asserted.

The bus state diagram in Figure 42 also applies to the use of $\overline{\text{BS16}}$. If the Am386DE microprocessor makes internal adjustments for 16-bit bus size, the adjustments do not affect the external bus states. If an additional 16-bit bus cycle is required to complete a transfer on a 16-bit bus, it also follows the state transitions shown in Figure 42.

Use of pipelined address allows the Am386DE CPU to enter three additional bus states not shown in Figure 42. Figure 48 is the complete bus state diagram, including pipelined address cycles.

Non-Pipelined Address With Dynamic Data Bus Sizing

The physical data bus width for any non-pipelined bus cycle can be either 32 or 16 bits. At the beginning of the bus cycle, the processor behaves as if the data bus is 32 bits wide. When the bus cycle is acknowledged by asserting $\overline{\text{READY}}$ at the end of a T2 state, the most recent sampling of $\overline{\text{BS16}}$ determines the data bus size for the cycle being acknowledged. If $\overline{\text{BS16}}$ was most recently negated, the physical data bus size is defined as 32 bits. If $\overline{\text{BS16}}$ was most recently asserted, the size is defined as 16 bits.

When $\overline{\text{BS16}}$ is asserted and two 16-bit bus cycles are required to complete the transfer, $\overline{\text{BS16}}$ must be asserted during the second cycle; 16-bit bus size is not assumed. Like any bus cycle, the second 16-bit cycle must be acknowledged by asserting $\overline{\text{READY}}$.

When a second 16-bit bus cycle is required to complete the transfer over a 16-bit bus, the addresses generated for the two 16-bit bus cycles are closely related to each other. The addresses are the same, except $\overline{BE0}$ and $\overline{BE1}$ are always negated for the second cycle. This is because data on D15–D0 was already transferred during the first 16-bit cycle.

Figure 43 and Figure 44 show cases where assertion of $\overline{BS16}$ requires a second 16-bit cycle for complete operation and transfer. Figure 43 illustrates cycles without wait states. Figure 44 illustrates cycles with one wait state. In Figure 44 Cycle 1, the bus cycle during which $\overline{BS16}$ is asserted, note that \overline{NA} must be negated in the T2 state(s) prior to the last T2 state. This is to allow the recognition of $\overline{BS16}$ asserted in the final T2 state. The relation of \overline{NA} and $\overline{BS16}$ is given fully in Pipelined Address, but Figure 44 illustrates this only precaution you need to know when using $\overline{BS16}$ with non-pipelined address.

Pipelined Address

Address pipelining is the option of requesting the address and the bus cycle definition of the next internally pending bus cycle before the current bus cycle is acknowledged with \overline{READY} asserted. \overline{ADS} is asserted by the Am386DE microprocessor when the next address is issued. The address pipelining option is controlled on a cycle-by-cycle basis with the \overline{NA} input signal.

Once a bus cycle is in progress and the current address has been valid for at least one entire bus state, the \overline{NA} input is sampled at the end of every phase one until the bus cycle is acknowledged. During non-pipelined bus cycles, therefore, \overline{NA} is sampled at the end of phase one in every T2. An example is Cycle 2 in Figure 45, during which \overline{NA} is sampled at the end of phase one of every T2 (it was asserted once during the first T2 and has no further effect during that bus cycle).

If \overline{NA} is sampled asserted, the Am386DE microprocessor is free to drive the address and bus cycle definition of the next bus cycle, and assert \overline{ADS} , as soon as it has a bus request internally pending. It may drive the next address as early as the next bus state, whether the current bus cycle is acknowledged at that time or not.

Regarding the details of address pipelining, the Am386DE CPU has the following characteristics.

1. For \overline{NA} to be sampled asserted, $\overline{BS16}$ must be negated at the sampling window (see Figure 56 Cycles 2 through 4, and Figure 46 Cycles 1 through 4). If \overline{NA} and $\overline{BS16}$ are both sampled asserted during the last T2 period of a bus cycle, $\overline{BS16}$ asserted has priority. Therefore, if both are asserted, the current bus size is taken to be 16 bits and the next address is not pipelined.
2. The next address may appear as early as the bus state after \overline{NA} was sampled asserted (see Figure 45

or Figure 46). In that case, state T2P is entered immediately. However, when there is not an internal bus request already pending, the next address will not be available immediately after \overline{NA} is asserted and T2I is entered instead of T2P (see Figure 47 Cycle 3). Provided the current bus cycle is not yet acknowledged by \overline{READY} asserted, T2P will be entered as soon as the Am386DE microprocessor does drive the next address. External hardware should therefore observe the \overline{ADS} output as confirmation the next address is actually being driven on the bus.

3. Once \overline{NA} is sampled asserted, the Am386DE microprocessor commits itself to the highest priority bus request that is pending internally. It can no longer perform another 16-bit transfer to the same address should $\overline{BS16}$ be asserted externally, so thereafter assumes the current bus size is 32 bits. Therefore, if \overline{NA} is sampled asserted within a bus cycle, $\overline{BS16}$ must be negated thereafter in that bus cycle (see Figure 45, Figure 46, Figure 47). Consequently, do not assert \overline{NA} during bus cycles that must have $\overline{BS16}$ driven asserted. See Dynamic Bus Sizing with Pipelined Address.
4. Any address which is validated by a pulse on the Am386DE CPU \overline{ADS} output will remain stable on the address pins for at least two processor clock periods. The Am386DE microprocessor cannot produce a new address more frequently than every two processor clock periods (see Figure 45, Figure 46, Figure 47).
5. Only the address and bus cycle definition of the very next bus cycle is available. The pipelining capability cannot look further than one bus cycle ahead (see Figure 47 Cycle 1).

The complete bus state transition diagram, including operation with pipelined address is given by Figure 48. Note it is a superset of the diagram for non-pipelined address only and the three additional bus states for pipelined address are drawn in bold.

The fastest bus cycle with pipelined address consists of just two bus states, T1P and T2P (recall for non-pipelined address it is T1 and T2). T1P is the first bus state of a pipelined cycle.

Initiating and Maintaining Pipelined Address

Using the state diagram Figure 48, observe the transitions from an idle state, T_i, to the beginning of a pipelined bus cycle, T1P. From an idle state T_i, the first bus cycle must begin with T1, and is therefore a non-pipelined bus cycle. The next bus cycle will be pipelined, however, provided \overline{NA} is asserted and the first bus cycle ends in a T2P state (the address for the next bus cycle is driven during T2P). The fastest path from an idle state to a bus cycle with pipelined address is shown in below:

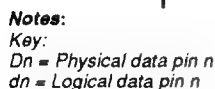
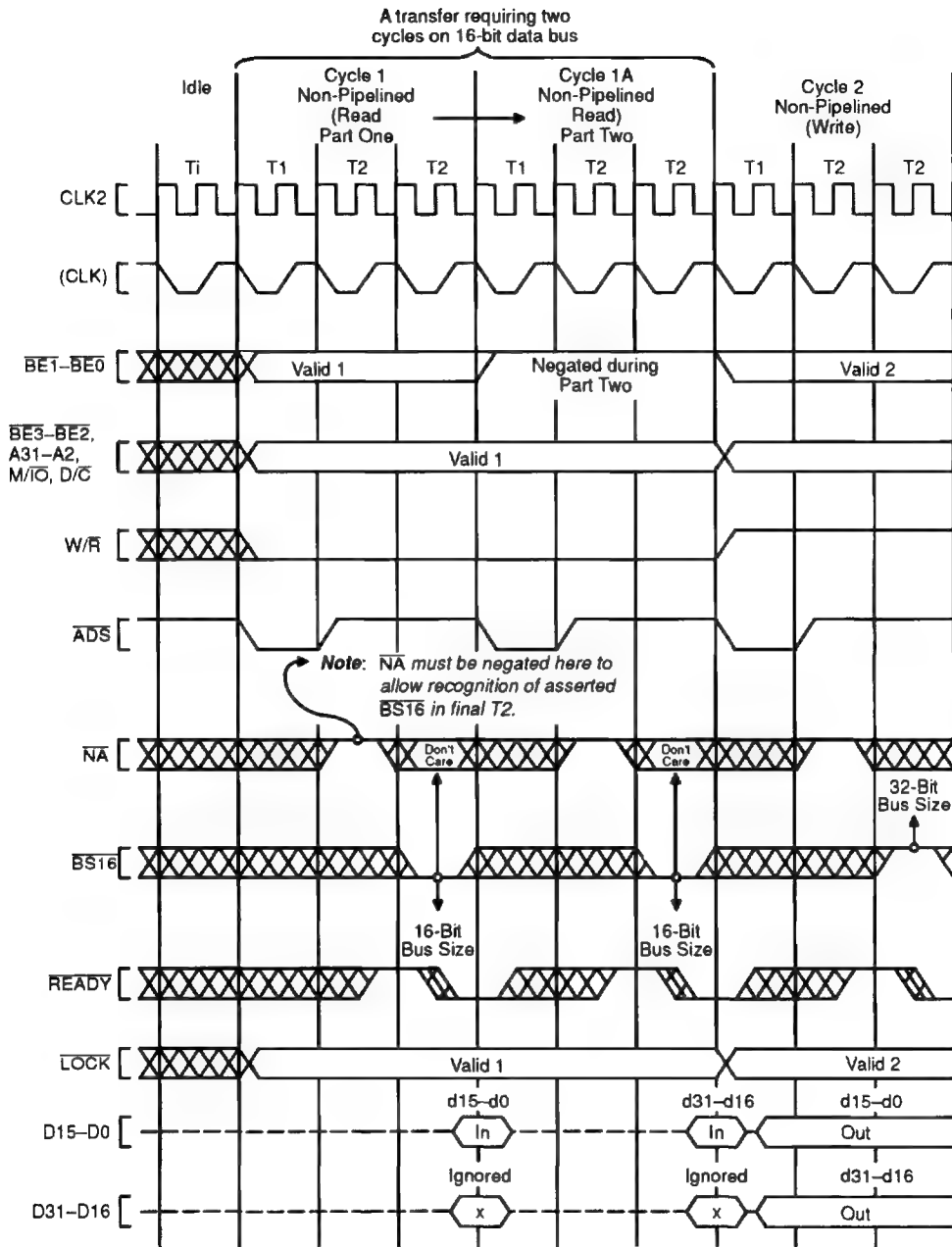
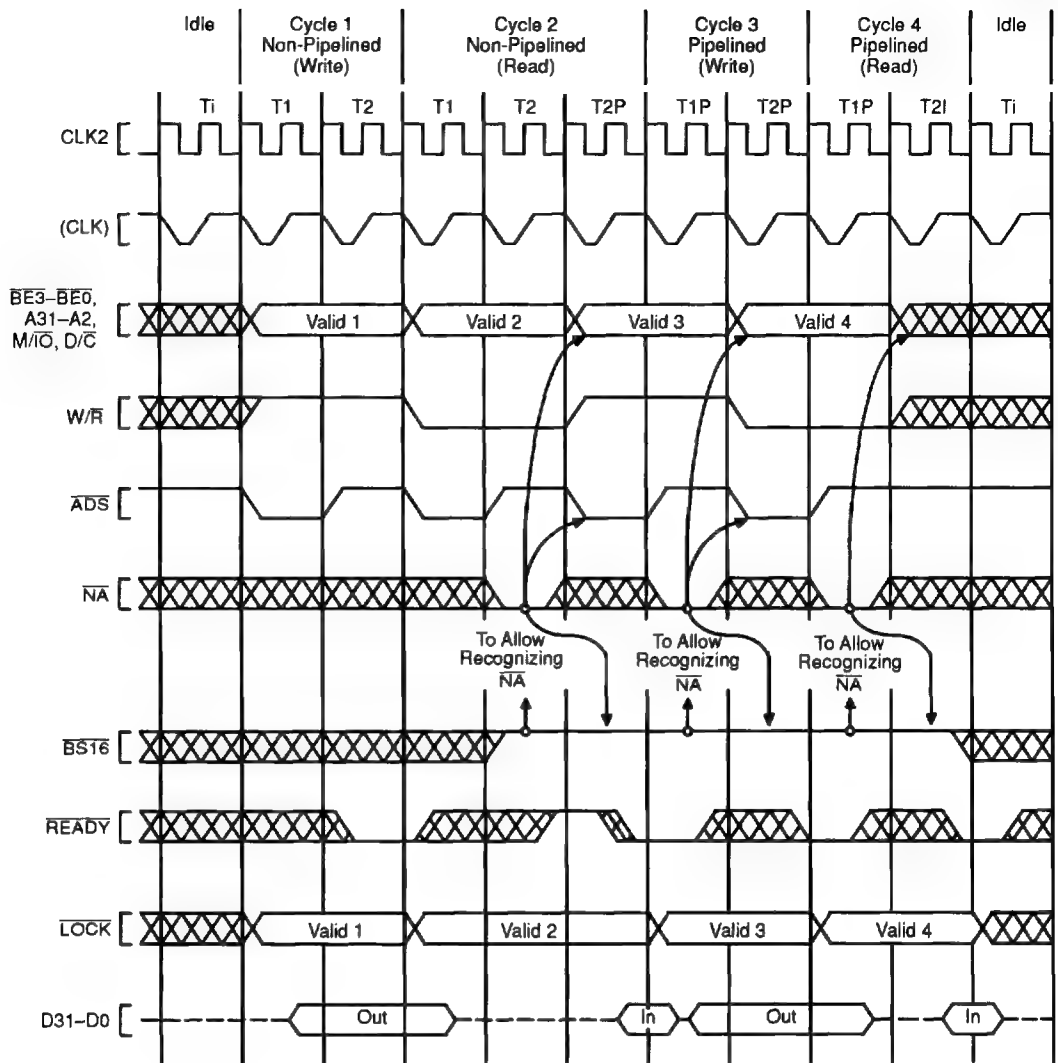


Figure 43. Asserting $\overline{\text{BS16}}$ (Zero-Wait-States, Non-Pipelined Address)



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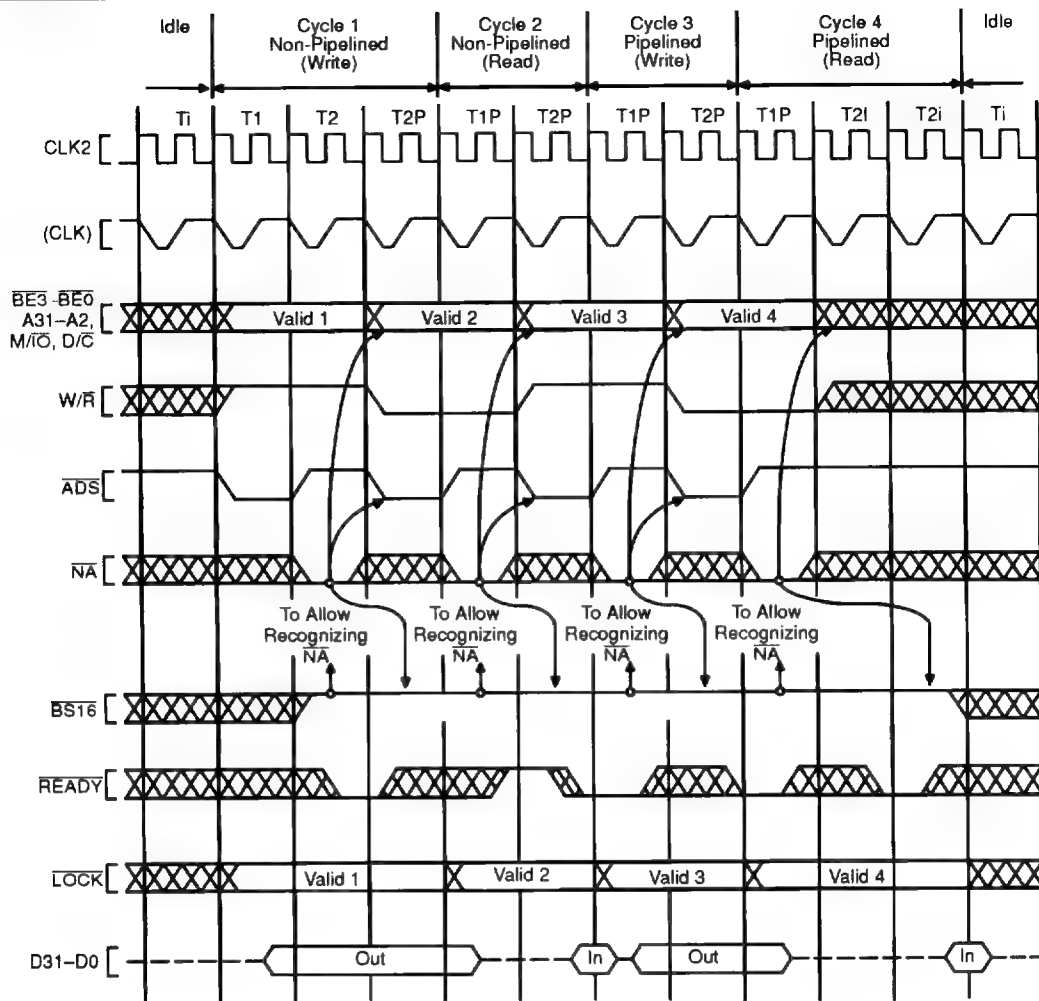
Figure 44. Asserting $\overline{BS16}$ (One-Wait-State, Non-Pipelined Address)

**Note:**

Following any idle bus state (T_i), addresses are non-pipelined. Within non-pipelined bus cycles, \overline{NA} is only sampled during wait states. Therefore, to begin address pipelining during a group of non-pipelined bus cycles requires a non-pipelined cycle with at least one wait state (Cycle 2 above).

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Figure 45. Transitioning to Pipelined Address During Burst of Bus Cycles

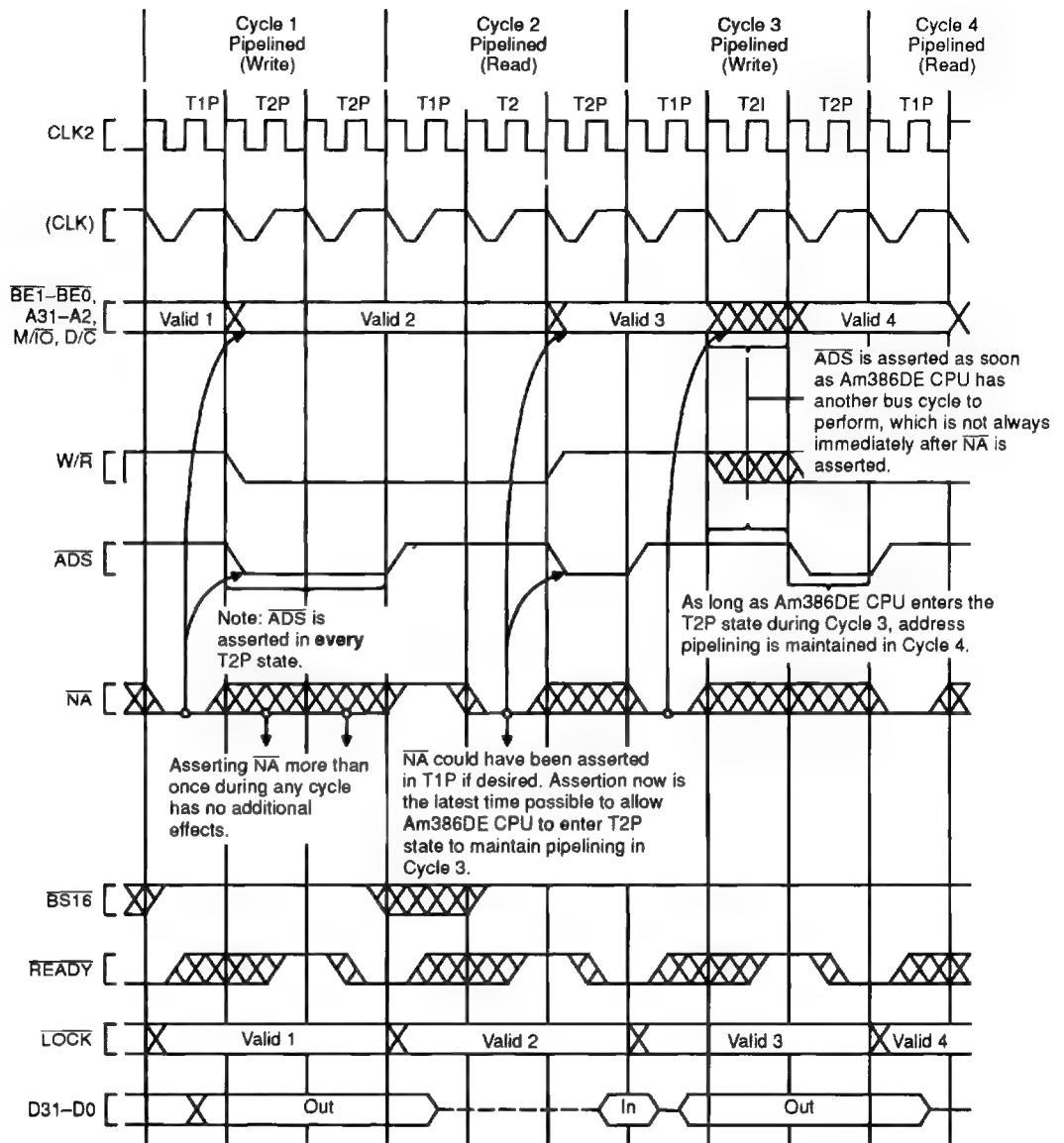


Note:

Following any idle bus state (Ti), the address is always non-pipelined and \overline{NA} is only sampled during wait states. To start address pipelining after an idle state requires a non-pipelined cycle with at least one wait state (Cycle 1 above). The pipelined cycles (2, 3, 4 above) are shown with various numbers of wait states.

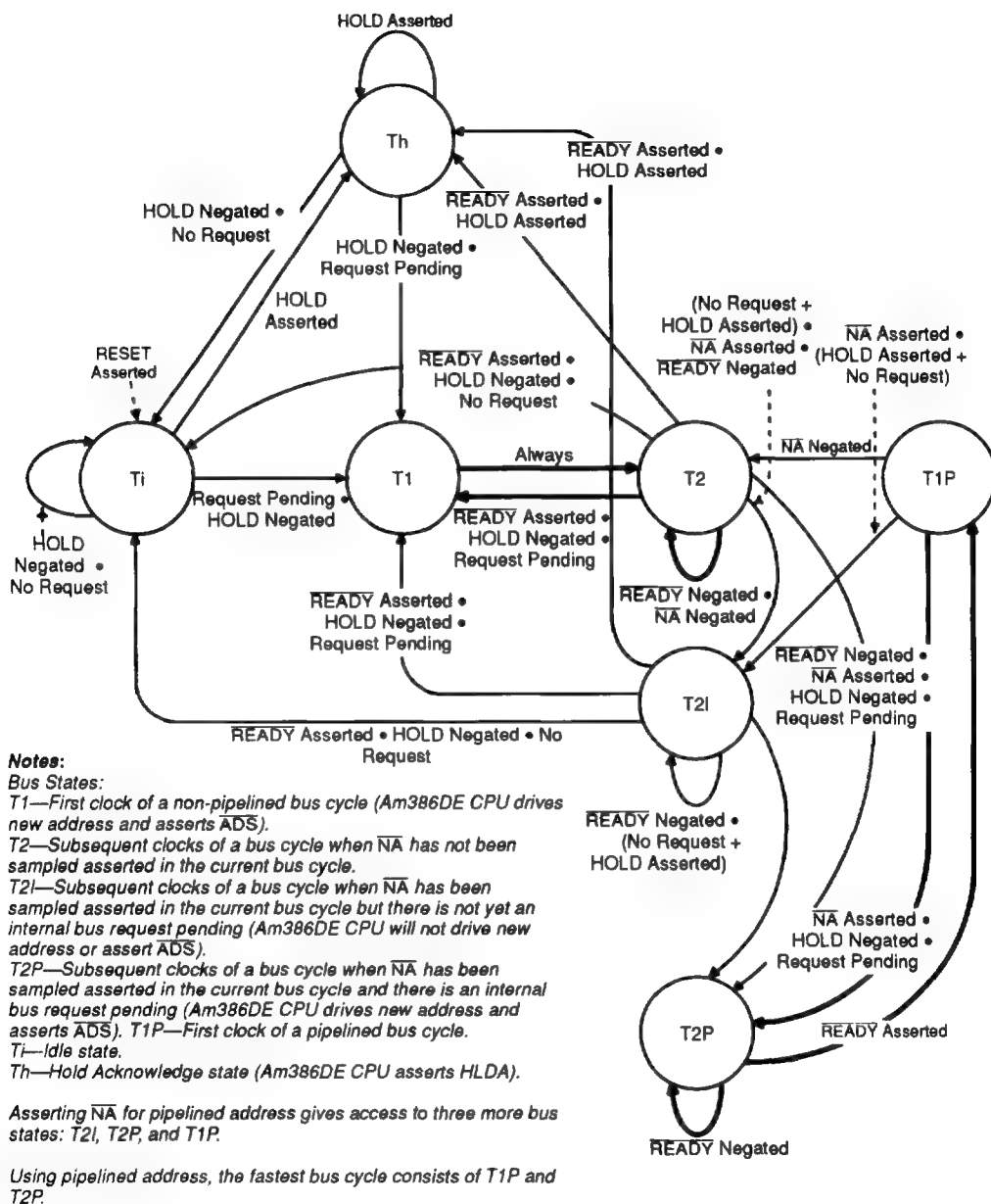
Figure 46. Fastest Transition to Pipelined Address Following Idle Bus State

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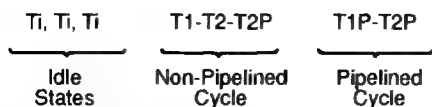
18421A-050

Figure 47. Details of Address Pipelining During Cycles with Wait States

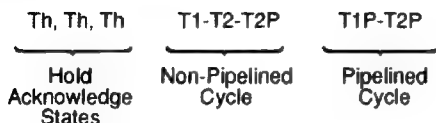


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Figure 48. Am386DE Microprocessor Complete Bus States (Including Pipelined Address)



T₁-T₂-T₂P are the states of the bus cycle that establishes address pipelining for the next bus cycle, which begins with T₁P. The same is true after a bus hold state, shown below:



The transition to pipelined address is shown functionally by Figure 46 Cycle 1. Note that Cycle 1 is used to transition into pipelined address timing for the subsequent Cycles 2, 3, and 4 that are pipelined. The \overline{NA} input is asserted at the appropriate time to select address pipelining for Cycles 2, 3, and 4.

Once a bus cycle is in progress and the current address has become valid, the \overline{NA} input is sampled at the end of every phase one, beginning with the next bus state, until the bus cycle is acknowledged. During Figure 46 Cycle 1 therefore, sampling begins in T₂. Once \overline{NA} is sampled asserted during the current cycle, the Am386DE microprocessor is free to drive a new address and bus cycle definition on the bus as early as the next bus state. In Figure 45 Cycle 1 for example, the next address is driven during state T₂P. Thus, Cycle 1 makes the transition to pipelined address timing, since it begins with T₁ but ends with T₂P. Because the address for Cycle 2 is available before Cycle 2 begins, Cycle 2 is called a pipelined bus cycle, and it begins with T₁P. Cycle 2 begins as soon as \overline{READY} asserted terminates Cycle 1.

Example transition bus cycles are Figure 46 Cycle 1 and Figure 45 Cycle 2. Figure 46 shows transition during the very first cycle after an idle bus state, which is the fastest possible transition into address pipelining. Figure 45 Cycle 2, shows a transition cycle occurring during a burst of bus cycles. In any case, a transition cycle is the same whenever it occurs: it consists at least of T₁, T₂ (you assert \overline{NA} at that time), and T₂P (provided the Am386DE microprocessor has an internal bus request already pending, which it almost always has). T₂P states are repeated if wait states are added to the cycle.

Note three states (T₁, T₂, and T₂P) are only required in a bus cycle performing a transition from non-pipelined address into pipelined address timing; for example, Figure 46 Cycle 1. Figure 46 Cycles 2, 3, and 4 show that address pipelining can be maintained with two-state bus cycles consisting only of T₁P and T₂P.

Once a pipelined bus cycle is in progress, pipelined timing is maintained for the next cycle by asserting \overline{NA} and detecting that the Am386DE CPU enters T₂P during the current bus cycle. The current bus cycle must end in state T₂P for pipelining to be maintained in the next cycle. T₂P is identified by the assertion of \overline{ADS} . Figure 45 and Figure 46 however, show pipelining ending after Cycle 4, because Cycle 4 ends in T₂P. This indicates the Am386DE CPU did not have an internal bus request prior to the acknowledgment of Cycle 4. If a cycle ends with a T₂ or T₂I, the next cycle will not be pipelined.

Realistically, address pipelining is almost always maintained as long as \overline{NA} is sampled asserted. This is so, because in the absence of any other request a code prefetch request is always internally pending until the instruction decoder and code prefetch queue are completely full. Therefore, address pipelining is maintained for long bursts of bus cycles, if the bus is available (i.e., \overline{HOLD} negated) and \overline{NA} is sampled asserted in each of the bus cycles.

Pipelined Address With Dynamic Data Bus Sizing

The $\overline{BS16}$ feature allows easy interface to 16-bit data buses. When asserted, the Am386DE microprocessor bus interface hardware performs appropriate action to make the transfer using a 16-bit data bus connected on D15-D0.

There is a degree of interaction, however, between the use of Address Pipelining and the use of Bus Size 16. The interaction results from the multiple bus cycles required when transferring 32-bit operands over a 16-bit bus. If the operand requires both 16-bit halves of the 32-bit bus, the appropriate Am386DE microprocessor action is a second bus cycle to complete the operand's transfer. This necessity conflicts with \overline{NA} usage.

When \overline{NA} is sampled asserted, the Am386DE microprocessor commits itself to perform the next internally pending bus request, and is allowed to drive the next internally pending address onto the bus. Asserting \overline{NA} therefore makes it impossible for the next bus cycle to again access the current address on A31-A2, such as may be required when $\overline{BS16}$ is asserted by the external hardware.

To avoid conflict, the Am386DE microprocessor is designed with the following two provisions.

1. To avoid conflict, $\overline{BS16}$ must be negated in the current bus cycle if \overline{NA} has already been sampled asserted in the current cycle. If \overline{NA} is sampled asserted, the current data bus size is assumed to be 32 bits.
2. Also to avoid conflict, if \overline{NA} and $\overline{BS16}$ are both asserted during the same sampling window, $\overline{BS16}$ asserted has priority and the Am386DE microprocessor acts as if \overline{NA} was negated at that time.

Certain types of 16- or 8-bit operands require no adjustment for correct transfer on a 16-bit bus. Those are read or write operands using only the lower half of the data bus, and write operands using only the upper half of the bus, since the Am386DE CPU simultaneously duplicates the write data on the lower half of the data bus. For these patterns of Byte Enables and the W/R signals, $\overline{BS16}$ need not be asserted at the Am386DE CPU allowing NA to be asserted during the bus cycle if desired.

Interrupt Acknowledge (INTA) Cycles

In response to an interrupt request on the INTR input when interrupts are enabled, the Am386DE microprocessor performs two interrupt acknowledge cycles. These bus cycles are similar to read cycles in that bus definition signals define the type of bus activity taking place, and each cycle continues until acknowledged by \overline{READY} sampled asserted.

The state of A2 distinguishes the first and second interrupt acknowledge cycles. The byte address driven during the first interrupt acknowledge cycle is 4 (A31–A3 Low, A2 High, BE3–BE1 High, and BE0 Low). The address driven during the second interrupt acknowledge cycle is 0 (A31–A2 Low, BE3–BE1 High, BE0 Low).

The \overline{LOCK} output is asserted from the beginning of the first interrupt acknowledge cycle until the end of the second interrupt acknowledge cycle. Four idle bus states, T1, are inserted by the Am386DE microprocessor between the two interrupt acknowledge cycles, allowing for compatibility with spec TRHRL of the 8259A Interrupt Controller.

During both interrupt acknowledge cycles, D31–D0 float. No data is read at the end of the first interrupt acknowledge cycle. At the end of the second interrupt acknowledge cycle, the Am386DE microprocessor will read an external interrupt vector from D7–D0 of the data bus. The vector indicates the specific interrupt number (from 0–255) requiring service.

Halt Indication Cycle

The Am386DE microprocessor halts as a result of executing a HALT instruction. Signaling its entrance into the halt state, a halt indication cycle is performed. The halt indication cycle is identified by the state of the bus definition signals shown in Bus cycle Definition and a byte address of 2. BE0 and BE2 are the only signals distinguishing halt indication from shutdown indication, that drives an address of 0. During the halt cycle undefined data is driven on D31–D0. The halt indication cycle must be acknowledged by \overline{READY} asserted.

A halted Am386DE CPU resumes execution when INTR (if interrupts are enabled) or NMI or RESET is asserted.

Shutdown Indication Cycle

The Am386DE microprocessor shuts down as a result of a protection fault while attempting to process a double fault. Signaling its entrance into the shutdown state, a shutdown indication cycle is performed. The shutdown indication cycle is identified by the state of the bus definition signals shown in Bus Cycle Definition and a byte address of 0. BE0 and BE2 are the only signals distinguishing shutdown indication from halt indication, which drives an address of 2. During the shutdown cycle, undefined data is driven on D31–D0. The shutdown indication cycle must be acknowledged by \overline{READY} asserted.

A shutdown Am386DE microprocessor resumes execution when NMI or RESET is asserted.

Other Functional Descriptions

Entering and Exiting Hold Acknowledge

The Bus Hold Acknowledge State, Th, is entered in response to the HOLD input being asserted. In the Bus Hold Acknowledge state, the Am386DE microprocessor floats all output or bidirectional signals, except for HLDA. HLDA is asserted as long as the Am386DE CPU remains in the bus hold acknowledge state. In the Bus Hold Acknowledge state, all inputs except HOLD, \overline{FLT} , RESET, BUSY, ERROR, and PEREQ are ignored (also up to one rising edge on NMI is remembered for processing when HOLD is no longer asserted).

Th may be entered from a bus idle state, as in Figure 53, or after the acknowledgment of the current physical bus cycle if the \overline{LOCK} signal is not asserted, as in Figure 54 and Figure 55. If HOLD is asserted during a locked bus cycle, the Am386DE microprocessor may execute one unlocked bus cycle before acknowledging HOLD. If asserting $\overline{BS16}$ requires a second 16-bit bus cycle to complete a physical operand transfer, it is performed before HOLD is acknowledged. Although the bus state diagrams in Figure 42 and Figure 48 do not indicate that detail.

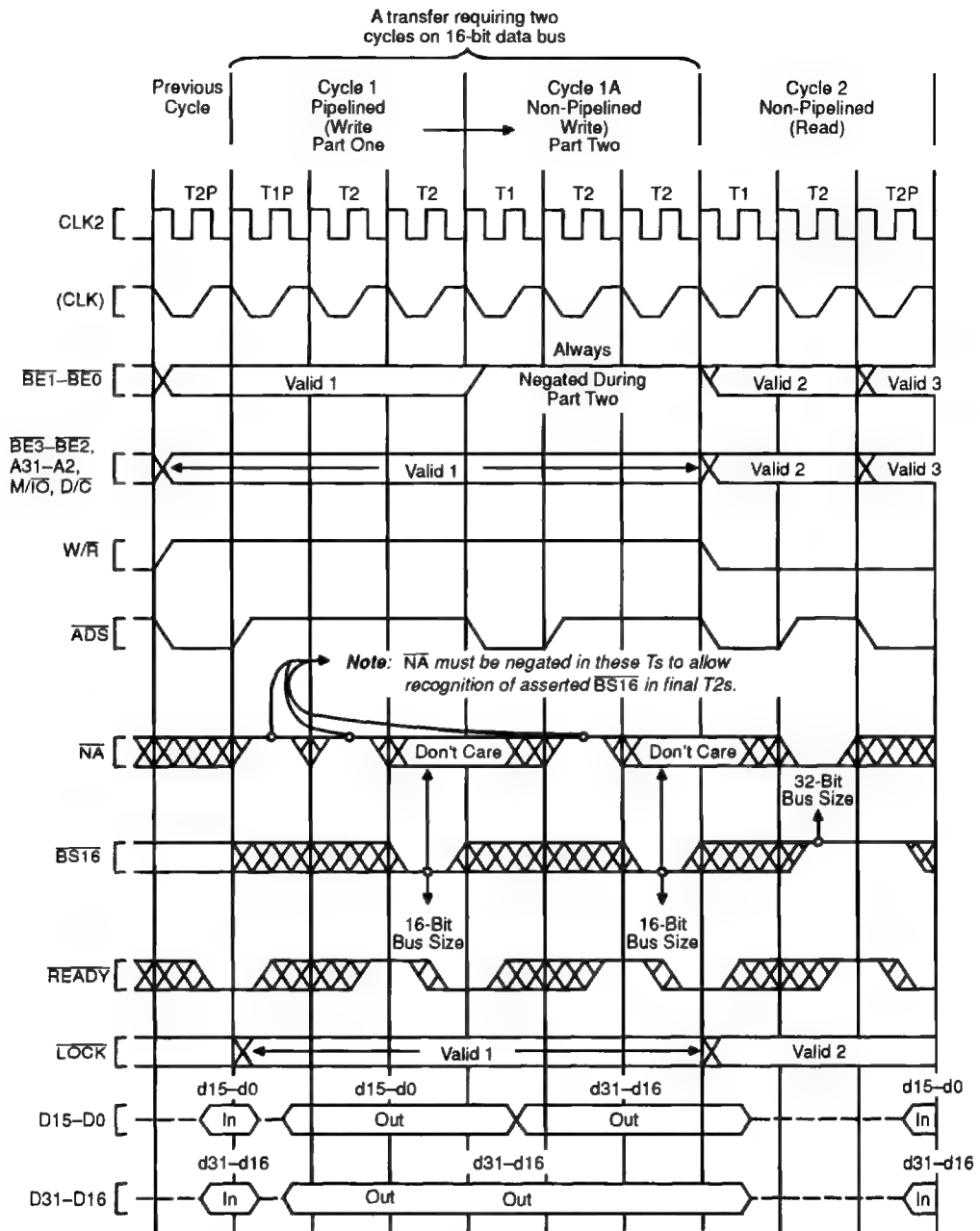
Th is exited in response to the HOLD input being negated. The following state will be T1 as in Figure 53 if no bus request is pending. The following bus state will be T1 if a bus request is internally pending, as in Figure 54 and Figure 55.

Th is also exited in response to RESET being asserted.

If a rising edge occurs on the edge-triggered NMI input while in Th, the event is remembered as a non-maskable interrupt 2 and is serviced when Th is exited, unless of course, the Am386DE microprocessor is reset before Th is exited.

RESET During HOLD Acknowledge

RESET being asserted takes priority over HOLD being asserted. Therefore, Th is exited in response to the

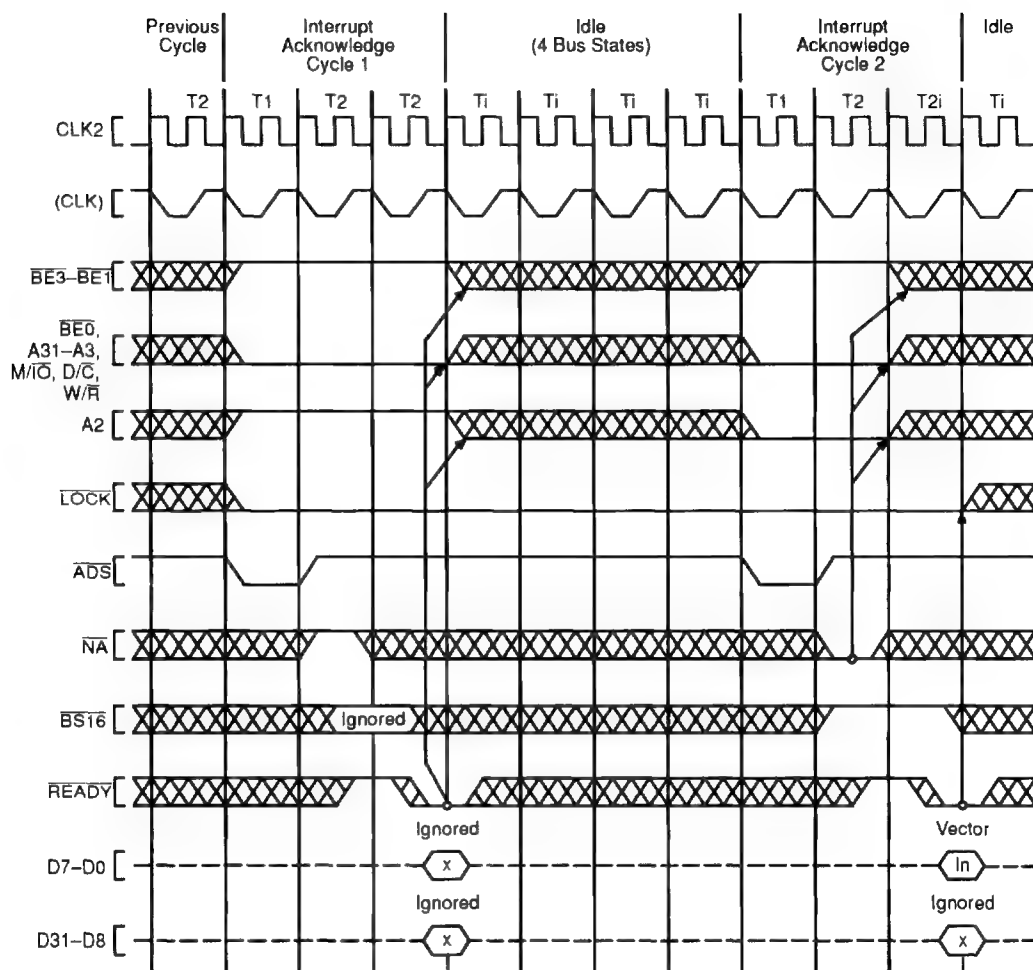
**Notes:**

Cycle 1 is pipelined. Cycle 1A cannot be pipelined, but its address can be inferred from that of Cycle 1, to externally simulate address pipelining during Cycle 1A.

Key: Dn = Physical data pin n
 dn = Logical data pin n

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Figure 49. Using \overline{NA} and $\overline{BS16}$



Note:

Interrupt Vector (0-255) is read on D7-D0 at end of second Interrupt Acknowledge bus cycle. Because each Interrupt Acknowledge bus cycle is followed by idle bus states, asserting NA has no practical effect. Choose the approach that is simplest for your system hardware design.

Figure 50. Interrupt Acknowledge Cycles

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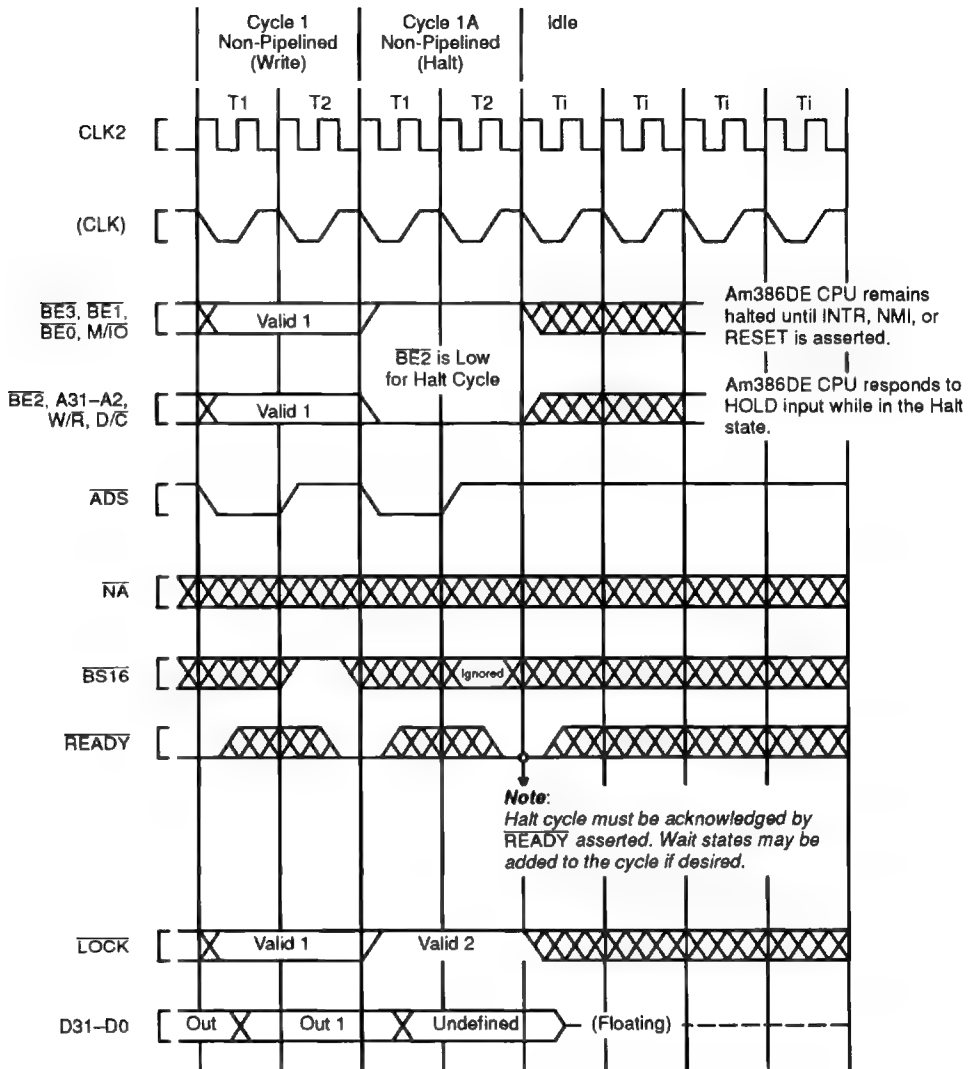


Figure 51. Halt Indication Cycle

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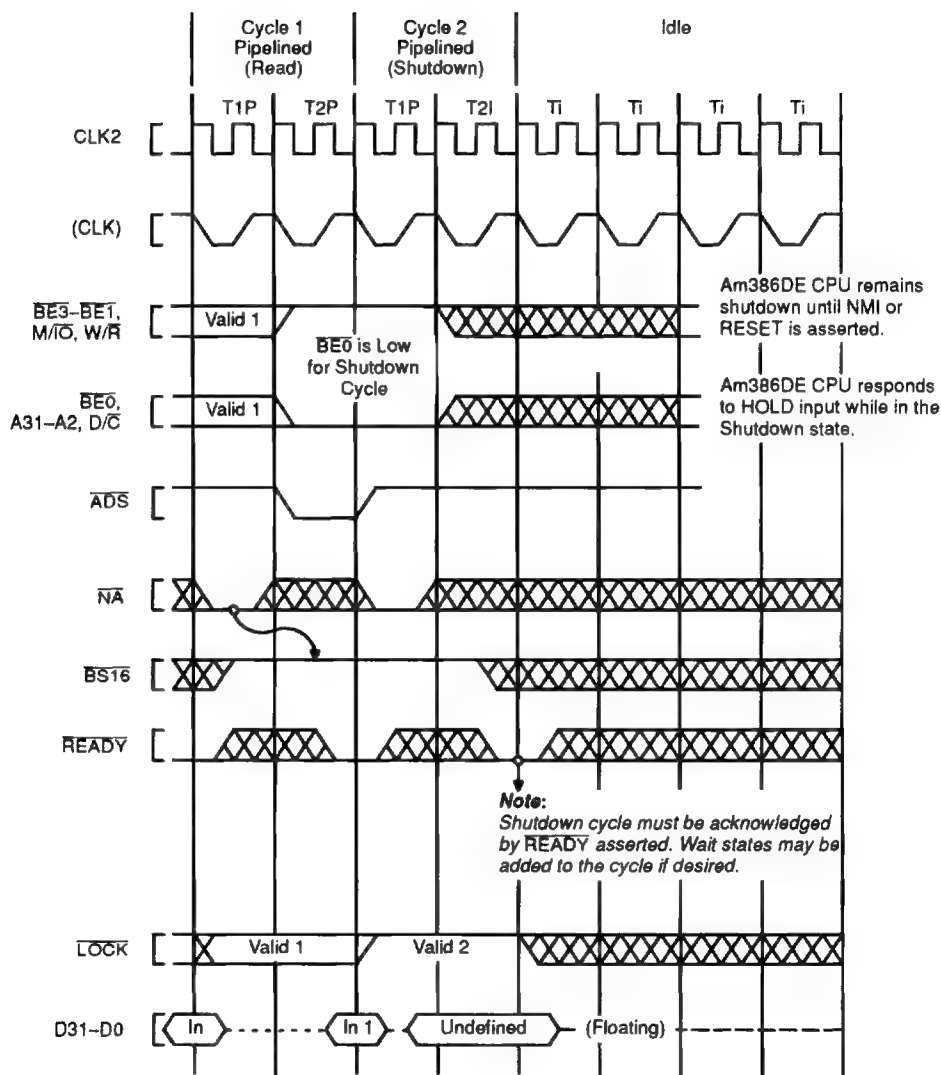
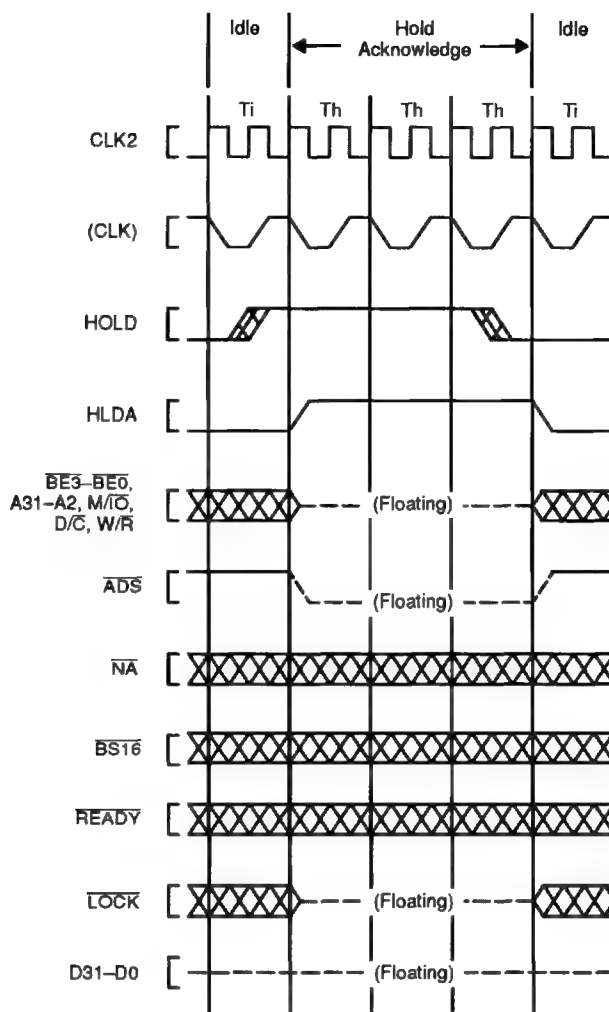


Figure 52. Shutdown Indication Cycle

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**Note:**

For maximum design flexibility, the Am386DE CPU has no internal pullup resistors on its outputs. The design may require an external pullup on \overline{ADS} and other Am386DE CPU outputs to keep them negated during float periods.

Figure 53. Requesting Hold from Idle Bus

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RESET input being asserted. If RESET is asserted while HOLD remains asserted, the Am386DE microprocessor drives its pins to defined states during reset, as in Table 15, Pin State During RESET, and performs internal reset activity as usual.

If HOLD remains asserted when RESET is negated, the Am386DE microprocessor enters the hold acknowledge

state before performing its first bus cycle, provided HOLD is still asserted when the Am386DE microprocessor would otherwise perform its first bus cycle. If HOLD remains asserted when RESET is negated, the \overline{BUSY} input is still sampled as usual to determine whether a self test is being requested, and ERROR is still sampled as usual to determine whether a 387DX math coprocessor versus an 80287 (or none) is present.

Float

Activating the $\overline{\text{FLT}}$ input floats all Am386DE CPU bidirectional and output signals, including HLDA. Asserting $\overline{\text{FLT}}$ isolates the Am386DE CPU from the surrounding circuitry.

As the Am386DE microprocessor is packaged in a surface mount PQFP, it cannot be removed from the motherboard when In-Circuit Emulation (ICE) is needed. The $\overline{\text{FLT}}$ input allows the Am386DE CPU to be electrically isolated from the surrounding circuitry. This allows connection of an emulator to the Am386DE microprocessor PQFP without removing it from the PCB. This method of emulation is referred to as ON-Circuit Emulation (ONCE).

Entering and Exiting Float

$\overline{\text{FLT}}$ is an asynchronous, active Low input. It is recognized on the rising edge of CLK2. When recognized, it aborts the current bus cycle and floats the outputs of the Am386DE microprocessor (Figure 57). $\overline{\text{FLT}}$ must be held Low for a minimum of 16 CLK2 cycles. Reset should be asserted and held asserted until after $\overline{\text{FLT}}$ is deasserted. This will ensure that the Am386DE CPU will exit Float in a valid state.

Asserting the $\overline{\text{FLT}}$ input unconditionally aborts the current bus cycle and forces the Am386DE microprocessor into the Float mode. Since activating $\overline{\text{FLT}}$ unconditionally forces the Am386DE CPU into Float mode, the Am386DE CPU is not guaranteed to enter Float in a valid state. After deactivating $\overline{\text{FLT}}$, the Am386DE CPU is not guaranteed to exit Float mode in a valid state. This is not a problem, as the $\overline{\text{FLT}}$ pin is meant to be used only during ONCE. After exiting Float, the Am386DE CPU must be reset to return it to a valid state. Reset should be asserted before $\overline{\text{FLT}}$ is deasserted. This will ensure that the Am386DE CPU will exit Float in a valid state.

$\overline{\text{FLT}}$ has an internal pull-up resistor, and if it is not used it should be unconnected.

Bus Activity During and Following Reset

RESET is the highest priority input signal capable of interrupting any processor activity when it is asserted. A bus cycle in progress can be aborted at any stage; or idle states or bus hold acknowledge states discontinued so that the RESET state is established.

RESET should remain asserted for at least 15 CLK2 periods to ensure it is recognized throughout the Am386DE microprocessor, and at least 80 CLK2 periods if Am386DE device self-test is going to be requested at the falling edge. RESET asserted pulses less than 15 CLK2 periods may not be recognized. RESET pulses less than 80 CLK2 periods followed by a self-test may cause the self-test to report a failure when no true failure exists.

The additional RESET pulse width is required to clear additional state prior to valid self-test.

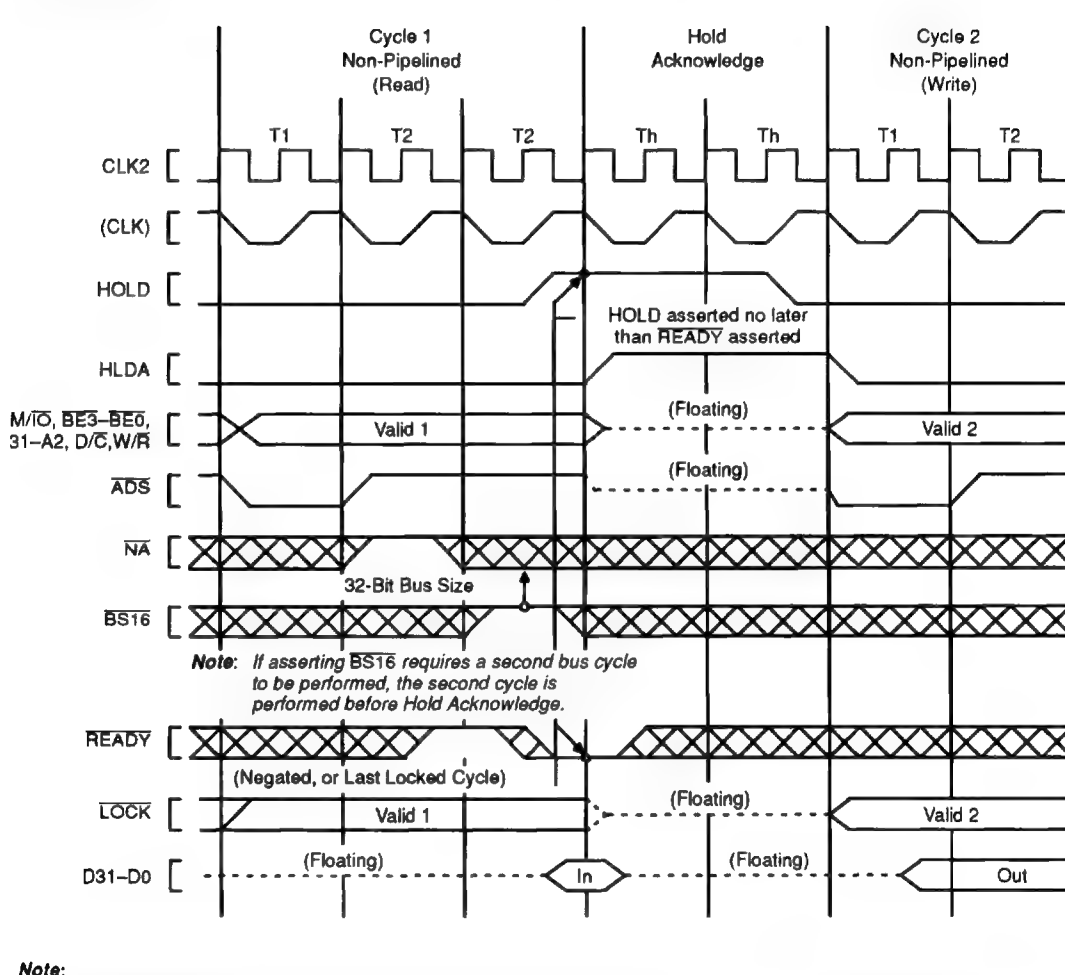
Provided the RESET falling edge meets setup and hold times, t25 and t26, the internal processor clock phase is defined at that time, as illustrated by Figure 67.

An Am386DE microprocessor self-test may be requested at the time RESET is negated by having the BUSY input at a Low level, as shown in Figure 56. The self-test requires $(2^{20}) +$ approximately 60 CLK2 periods to complete. The self-test duration is not affected by the test results. Even if the self-test indicates a problem, the Am386DE device attempts to proceed with the reset sequence afterward.

After the RESET falling edge (and after the self-test if it was requested) the Am386DE microprocessor performs an internal initialization sequence for approximately 350 to 450 CLK2 periods.

The Am386DE microprocessor samples its **ERROR** input some time after the falling edge of RESET and before executing the first ESC instruction. During this

sampling period **BUSY** must be High. If **ERROR** was sampled active, the Am386DE device employs the 32-bit protocol of a 387DX math coprocessor. Even though this protocol was selected, it is still necessary to use a software recognition test to determine the presence or identity of the coprocessor and to assure compatibility with future processors.

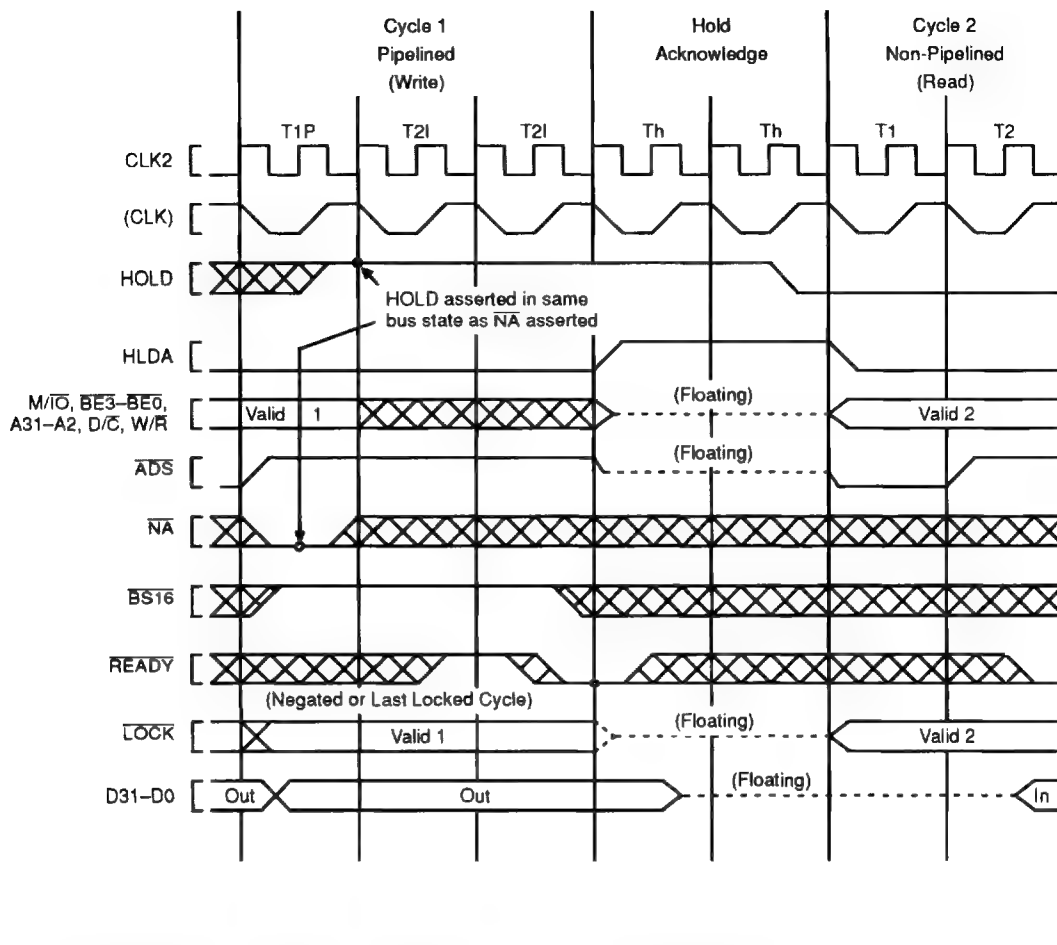


Note:

HOLD is a synchronous input and can be asserted at any **CLK2** edge, provided setup and hold (t_{23} and t_{24}) requirements are met. This waveform is useful for determining Hold Acknowledge latency.

Figure 54. Requesting Hold from Active Bus (NA** Negated)**

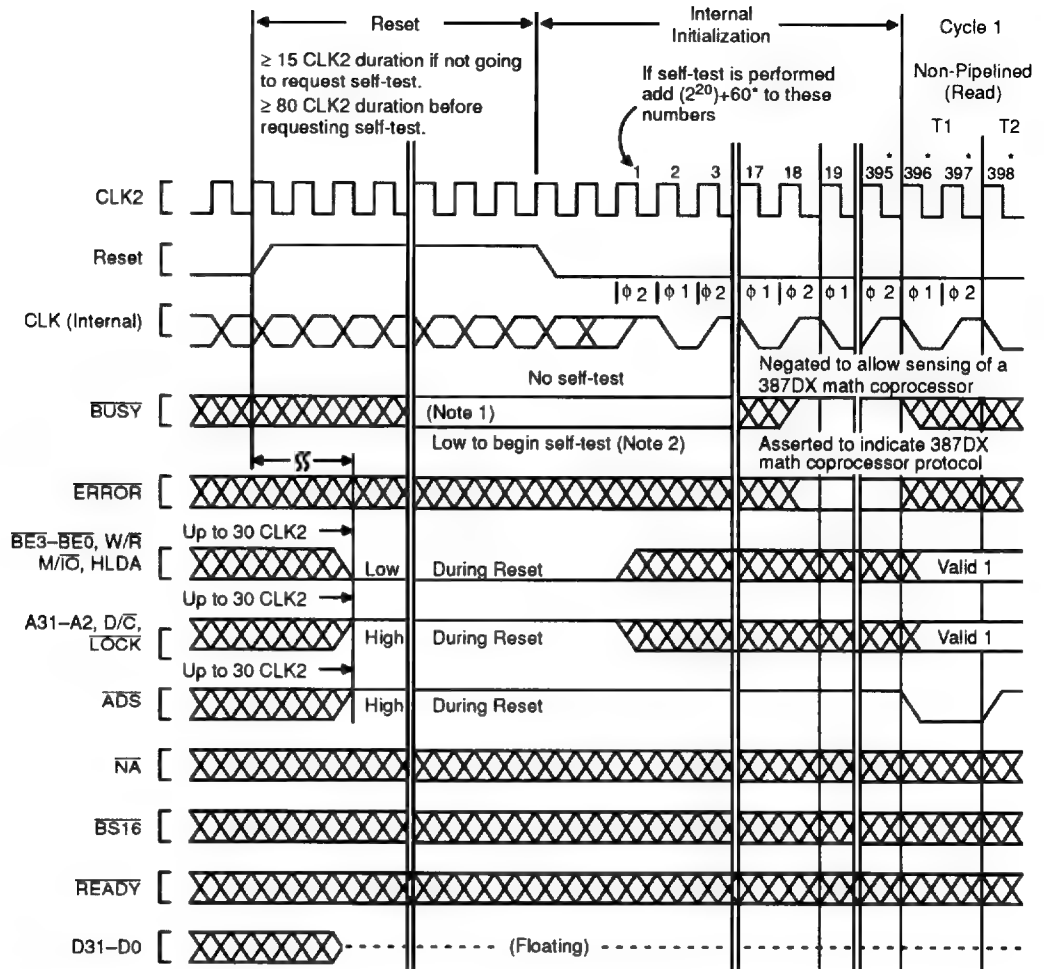
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Note:
HOLD is a synchronous input and can be asserted at any CLK2 edge, provided setup and hold (t23 and t24) requirements are met. This waveform is useful for determining Hold Acknowledge latency.

Figure 55. Requesting Hold from Active Bus (\overline{NA} Asserted)

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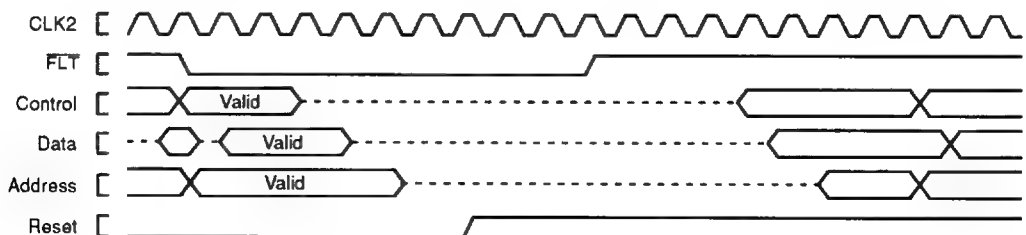
**Notes:**

*Approximately

1. BUSY should be held stable for 8 CLK2 periods before and after the CLK2 period in which RESET falling edge occurs.
2. If self-test is requested, the Am386DE microprocessor outputs remain in their reset state as shown here and in Table 14.

Figure 56. Bus Activity from Reset Until First Code Fetch

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**Figure 57. Entering and Exiting FLT**

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Self-Test Signature

Upon completion of self-test, (if self-test was requested by holding **BUSY** Low at least eight CLK2 periods before and after the falling edge of **RESET**), the **EAX** register will contain a signature of 00000000h indicating the Am386DE CPU passed its self-test of microcode and major PLA contents with no problems detected. The passing signature in **EAX**, 00000000h, applies to all Am386DE microprocessor revision levels. Any non-zero signature indicates the Am386DE CPU unit is faulty.

Component and Revision Identifiers

To assist Am386DE microprocessor users, the microprocessor after reset holds a component identifier and a revision identifier in its **DX** register. The Am386DE microprocessor, after reset, holds a component identifier and revision identifier in its **DX** register. In the **DH** portion, the lower nibble 3H refers to the Am386 CPU architecture. In the lower **DL** portion, the upper nibble **EH** identifies the processor as a member of the Am386 E CPU series. The lower nibble holds the unsigned binary number related to the component revision level. The revision identifier begins chronologically with a value zero and is subject to change (typically it will be incremented) with component steppings intended to have certain improvements or distinctions from previous steppings.

These features are intended to assist Am386DE microprocessor users to a practical extent. However, the revision identifier value is not guaranteed to change with every stepping revision nor to follow a completely uniform numerical sequence, depending on the type or intention of revision or manufacturing materials required to be changed.

Coprocessor Interfacing

The Am386DE microprocessor provides an automatic interface for coprocessor, like a 387DX compatible floating-point math coprocessor. A 387DX math coprocessor uses an I/O-mapped interface driven automatically by the Am386DE microprocessor and assisted by three dedicated signals: **BUSY**, **ERROR**, and **PEREQ**.

As the Am386DE CPU begins supporting a coprocessor instruction, it tests the **BUSY** and **ERROR** signals to determine if the coprocessor can accept its next instruction. Thus, the **BUSY** and **ERROR** inputs eliminate the need for any preamble bus cycles for communication between processor and coprocessor. A 387DX math coprocessor can be given its command op-code immediately. The dedicated signals provide instruction synchronization, and eliminate the need of using the Am386DE CPU **WAIT** op-code (9Bh) for 387DX math coprocessor instruction synchronization (the **WAIT** op-code was required when 8086 or 8088 was used with the 8087 coprocessor).

Custom coprocessors can be included in Am386DE microprocessor-based systems, via memory-mapped or I/O-mapped interfaces. Such coprocessor interfaces allow a completely custom protocol, and are not limited to a set of coprocessor protocol primitives. Instead, memory-mapped or I/O-mapped interfaces may use all applicable Am386DE microprocessor instructions for high-speed coprocessor communication. The **BUSY** and **ERROR** inputs of the Am386DE CPU may also be used for the custom coprocessor interface, if such hardware assist is desired. These signals can be tested by the Am386DE CPU **WAIT** op-code (9Bh). The **WAIT** instruction will wait until the **BUSY** input is negated (interruptable by an **NMI** or enable **INTR** input), but generates an Exception 16 fault if the **ERROR** pin is in the asserted state when the **BUSY** goes (or is) negated. If the custom coprocessor interface is memory-mapped, protection of the addresses used for the interface can be provided with the Am386DE microprocessor on-chip segmentation mechanisms. If the custom interface is I/O-mapped, protection of the interface can be provided with the Am386DE microprocessor **IOPL** (I/O Privilege Level) mechanism.

A 387DX math coprocessor interface is I/O mapped as shown in Table 23. Note that a 387DX math coprocessor interface addresses are beyond the 0hFFFFh range for programmed I/O. When the Am386DE CPU supports a 387DX math coprocessor, the Am386DE microprocessor automatically generates bus cycles to the coprocessor interface addresses.

Table 23. Math Coprocessor Port Addresses

Address in Am386DE CPU I/O Space	387DX Coprocessor Register
800000F8h	Opcode Register (32-bit port)
800000FCh	Operand Register (32-bit port)

To correctly map the 387DX math coprocessor registers to the appropriate I/O addresses, connect a 387DX math coprocessor **CD0** pin directly to the **A2** output of the Am386DE microprocessor.

Software Testing for Coprocessor Presence

When software is used to test for coprocessor (387DX) presence, it should use only the following coprocessor op-codes: **FINIT**, **FNINIT**, **FSTCW** mem, **FSTSW** mem, **FSTSW** AX. To use other coprocessor op-codes when a coprocessor is known to be not present, first set **EM** = 1 in Am386DE microprocessor **CR0**.

ABSOLUTE MAXIMUM RATINGS

Storage Temperature -65°C to +150°C
 Ambient Temperature Under Bias . . -65°C to +125°C

Stresses above those listed may cause permanent device failure. Functionality at or above these limits is not implied. Exposure to ABSOLUTE MAXIMUM RATINGS for extended periods may affect device reliability.

OPERATING RANGES

Supply Voltage with Respect to V_{SS} ... -0.5 V to +7 V
 Voltage on Other Pins -0.5 V to $V_{CC} + 0.5$ V

Operating ranges define those limits between which the functionality of the device is guaranteed.

DC CHARACTERISTICS over COMMERCIAL Operating Ranges (PQFP, 33 MHz)

$V_{CC} = 3.0$ V to 3.6 V; $T_{CASE} = 0^\circ\text{C}$ to $+100^\circ\text{C}$ (Extended Temperature, $T_{CASE} = -40^\circ\text{C}$ to 100°C)

Symbol	Parameter Description	Notes	Preliminary		Unit
			Min	Max	
V_{IL}	Input Low Voltage	(Note 1)	-0.3	0.8	V
V_{IH}	Input High Voltage		2.0	$V_{CC} + 0.3$	V
V_{ILC}	CLK2 Input Low Voltage	(Note 1)	-0.3	0.8	V
V_{IHC}	CLK2 Input High Voltage (25 MHz)		2.4	$V_{CC} + 0.3$	V
V_{OL}	Output Low Voltage	(Note 5)			
	$I_{OL} = 0.5$ mA: A31-A2, D31-D0			0.2	V
	$I_{OL} = 0.5$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA			0.2	V
	$I_{OL} = 2$ mA: A31-A2, D31-D0			0.45	V
	$I_{OL} = 2.5$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA			0.45	V
V_{OH}	Output High Voltage	(Note 5)			
	$I_{OH} = 0.1$ mA: A31-A2, D31-D0		$V_{CC} - 0.2$		V
	$I_{OH} = 0.1$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA		$V_{CC} - 0.2$		V
	$I_{OH} = 0.5$ mA: A31-A2, D31-D0		$V_{CC} - 0.45$		V
	$I_{OH} = 0.5$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA		$V_{CC} - 0.45$		V
I_{LI}	Input Leakage Current (All pins except BS16, PEREQ, BUSY, FLT, and ERROR)	$0 \text{ V} \leq V_{IN} \leq V_{CC}$		± 10	μA
I_{IH}	Input Leakage Current (PEREQ Pin)	$V_{IH} = V_{CC} - 0.1$ V $V_{IH} = 2.4$ V (Note 2)		300 200	μA
I_{IL}	Input Leakage Current (BS16, BUSY, FLT, and ERROR)	$V_{IL} = 0.1$ V $V_{IL} = 0.45$ V (Note 3)		-300 -200	μA
I_{LO}	Output Leakage Current	$0.1 \text{ V} \leq V_{OUT} \leq V_{CC}$		± 15	μA
I_{CC}	Supply Current (Note 6)	$V_{CC} = 3.3$ V		$V_{CC} = 3.6$ V	
	CLK2 = 50 MHz: Oper. Freq. 25 MHz	I_{CC} Typ = 95		115	mA
	CLK2 = 66 MHz: Oper. Freq. 33 MHz	I_{CC} Type = TBD		TBD	mA
I_{CCSB}	Standby Current (Note 6)	I_{CCSB} Typ = 10 μA		150	μA
C_{IN}	Input or I/O Capacitance	$F_C = 1$ MHz (Note 4)		10	pF
C_{OUT}	Output Capacitance	$F_C = 1$ MHz (Note 4)		12	pF
C_{CLK}	CLK2 Capacitance	$F_C = 1$ MHz (Note 4)		20	pF

Notes:

1. The Min value, -0.3, is not 100% tested.
2. PEREQ input has an internal pull-down resistor.
3. BS16, BUSY, FLT, and ERROR inputs each have an internal pull-up resistor.
4. Not 100% tested.
5. Outputs are CMOS and will pull rail-to-rail if the load is not resistive.
6. Inputs are at either V_{CC} or V_{SS} .

ABSOLUTE MAXIMUM RATINGS

Storage Temperature -65°C to +150°C
Ambient Temperature Under Bias -65°C to +125°C

Stresses above those listed may cause permanent device failure. Functionality at or above these limits is not implied. Exposure to ABSOLUTE MAXIMUM RATINGS for extended periods may affect device reliability.

OPERATING RANGES

Supply Voltage with Respect to V_{SS} -0.5 V to +7 V
Voltage on Other Pins -0.5 V to $V_{CC} + 0.5$ V

Operating ranges define those limits between which the functionality of the device is guaranteed.

DC CHARACTERISTICS over COMMERCIAL Operating Ranges (PQFP, 33 MHz)

$V_{CC} = 3.0$ V to 5.5 V; $T_{CASE} = 0^\circ\text{C}$ to $+100^\circ\text{C}$ (Extended Temperature, $T_{CASE} = -40^\circ\text{C}$ to 100°C)

Symbol	Parameter Description	Notes	Preliminary		Unit
			Min	Max	
V_{IL}	Input Low Voltage	(Note 1)	-0.3	0.8	V
V_{IH}	Input High Voltage		2.0	$V_{CC} + 0.3$	V
V_{ILC}	CLK2 Input Low Voltage	(Note 1)	-0.3	0.8	V
V_{IHC}	CLK2 Input High Voltage (33 MHz)		2.7	$V_{CC} + 0.3$	V
V_{OL}	Output Low Voltage $I_{OL} = 4$ mA: A31-A2, D31-D0 $I_{OL} = 5$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA	(Note 5)		0.45	V
				0.45	V
V_{OH}	Output High Voltage $I_{OH} = 1$ mA: A31-A2, D31-D0 $I_{OH} = 0.9$ mA: BE3-BE0, W/R, D/C, M/I/O, LOCK, ADS, HLDA	(Note 5)	2.4		V
			2.4		V
I_{LI}	Input Leakage Current (All pins except BS16, PEREQ, BUSY, FLT, and ERROR)	$0 \text{ V} \leq V_{IN} \leq V_{CC}$		± 15	μA
I_{IH}	Input Leakage Current (PEREQ Pin)	$V_{IH} = 2.4$ V (Note 2)		200	μA
I_{IL}	Input Leakage Current (BS16, BUSY, FLT, and ERROR)	$V_{IL} = 0.45$ (Note 3)		-400	μA
I_{LO}	Output Leakage Current	$0.45 \text{ V} \leq V_{OUT} \leq V_{CC}$		± 15	μA
I_{CC}	Supply Current (Note 6) CLK2 = 50 MHz: Oper. Freq. 25 MHz CLK2 = 66 MHz: Oper. Freq. 33 MHz	$V_{CC} = 5.0$ V		$V_{CC} = 5.5$ V	
		I_{CC} Typ = 160		190	mA
		I_{CC} Typ = 210		245	mA
I_{CCSB}	Standby Current (Note 6)	I_{CCSB} Typ = 20 μA		150	μA
C_{IN}	Input or I/O Capacitance	$F_C = 1$ MHz (Note 4)		10	pF
C_{OUT}	Output Capacitance	$F_C = 1$ MHz (Note 4)		12	pF
C_{CLK}	CLK2 Capacitance	$F_C = 1$ MHz (Note 4)		20	pF

Notes:

1. The Min value, -0.3, is not 100% tested.
2. PEREQ input has an internal pull-down resistor.
3. BS16, BUSY, FLT, and ERROR inputs each have an internal pull-up resistor.
4. Not 100% tested.
5. Outputs are CMOS and will pull rail-to-rail if the load is not resistive.
6. Inputs are at either V_{CC} or V_{SS} .

SWITCHING CHARACTERISTICS over COMMERCIAL operating range — 33 MHz $V_{CC} = 3.0\text{--}5.5\text{ V}$; $T_{CASE} = 0^{\circ}\text{C}$ to $+100^{\circ}\text{C}$ (PQFP)(Extended Temperature $T_{CASE} = -40^{\circ}\text{C}$ to 100°C)

No.	Parameter Description	Notes	Ref Figure	Min	Max	Unit
	Oper. Frequency: Am386DE CPU	Half CLK2 freq.		0	33.3	MHz
1	CLK2 Period: Am386DE CPU		60	15		ns
2	CLK2 High Time	at V_{IH}	60	4		ns
3	CLK2 Low Time	at 0.8 V	60	5		ns
4	CLK2 Fall Time	2.7 V–0.8 V (Note 3)	60		4	ns
5	CLK2 Rise Time	0.8 V–2.7 V (Note 3)	60		4	ns
6	A31–A2 Valid Delay	$C_L = 50\text{ pF}$	62	4	15	ns
7	A31–A2 Float Delay	(Note 1)	69	4	20	ns
8	$\overline{BE}3\text{--}\overline{BE}0$, \overline{LOCK} Valid Delay	$C_L = 50\text{ pF}$	62	4	15	ns
9	$\overline{BE}3\text{--}\overline{BE}0$, \overline{LOCK} Float Delay	(Note 1)	69	4	20	ns
10	$\overline{W}/\overline{R}$, $\overline{M}/\overline{IO}$, $\overline{D}/\overline{C}$ Valid Delay	$C_L = 50\text{ pF}$	62	4	15	ns
10a	\overline{ADS} Valid Delay	$C_L = 50\text{ pF}$	62	4	14.5	ns
11	$\overline{W}/\overline{R}$, $\overline{M}/\overline{IO}$, $\overline{D}/\overline{C}$, \overline{ADS} Float Delay	(Note 1)	69	4	20	ns
12	D31–D0 Write Data Valid Delay	$C_L = 50\text{ pF}$ (Note 4)	63	7	23	ns
12a	D31–D0 Write Data Hold Time	$C_L = 50\text{ pF}$	64	2		ns
13	D31–D0 Float Delay	(Note 1)	69	4	17	ns
14	HLDA Valid Delay	$C_L = 50\text{ pF}$	62, 69	4	20	ns
14f	HLDA Float Delay	(Note 1)	69	4	20	ns
15	\overline{NA} Setup Time		61	5		ns
16	\overline{NA} Hold Time		61	2		ns
17	$\overline{BS}16$ Setup Time		61	5		ns
18	$\overline{BS}16$ Hold Time		61	2		ns
19	\overline{READY} Setup Time		61	7		ns
20	\overline{READY} Hold Time		61	4		ns
21	D31–D0 Read Setup Time		61	5		ns
22	D31–D0 Read Hold Time		61	3		ns
23	HOLD Setup Time		61	9		ns
24	HOLD Hold Time		61	2		ns
25	RESET Setup Time		70	5		ns
26	RESET Hold Time		70	2		ns
27	NMI, INTR Setup Time	(Note 2)	61	5		ns
28	NMI, INTR Hold Time	(Note 2)	61	5		ns
29	\overline{PEREQ} , \overline{ERROR} , \overline{BUSY} , \overline{FLT}^* Setup Time	(Note 2)	61	5		ns
30	\overline{PEREQ} , \overline{ERROR} , \overline{BUSY} , \overline{FLT}^* Hold Time	(Note 2)	61	4		ns

Notes:

*PQFP package only.

1. Float condition occurs when maximum output current becomes less than I_{LO} in magnitude. Float delay is not 100% tested.
2. These inputs are allowed to be asynchronous to CLK2. The setup and hold specifications are given for testing purposes, to assure recognition within a specific clock period.
3. Rise and fall times are not tested.
4. Min time not 100% tested.

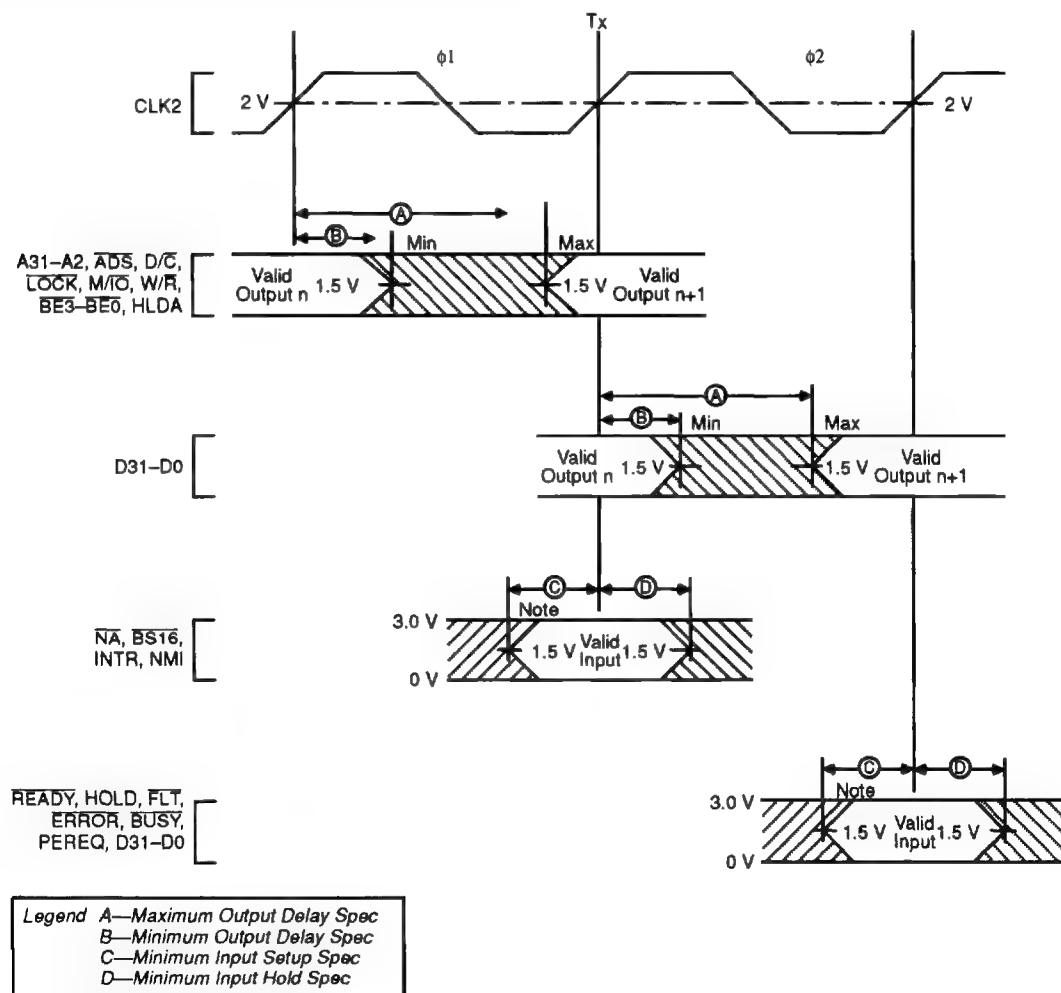
SWITCHING WAVEFORMS

The switching characteristics consist of output delays, input setup requirements, and input hold requirements. All characteristics are relative to the CLK2 rising edge crossing the 2.0 V level.

Switching characteristic measurement is defined by Figure 58. Inputs must be driven to the voltage levels indicated by this diagram. Am386DE CPU output delays are specified with minimum and maximum limits measured as shown. The minimum Am386DE microprocessor delay times are hold times provided to external circuitry. Am386DE microprocessor input setup and hold time are specified as minimums, defining the

smallest acceptable sampling window. Within the sampling window, a synchronous input signal must be stable for correct Am386DE microprocessor operation.

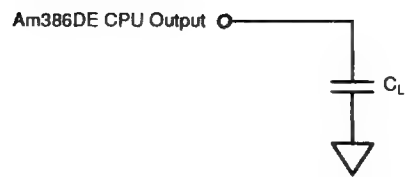
Outputs \overline{ADS} , W/R , D/C , M/\overline{IO} , \overline{LOCK} , $BE3$ – $BE0$, $A31$ – $A2$, and $HLDA$ only change at the beginning of phase one. $D31$ – $D0$ (write cycles) only change at the beginning of phase two. The $READY$, $HOLD$, $BUSY$, \overline{ERROR} , $PEREQ$, \overline{FLT} , and $D31$ – $D0$ (read cycles) inputs are sampled at the beginning of phase one. The \overline{NA} , $\overline{BS16}$, $INTR$, and NMI inputs are sampled at the beginning of phase two.



Note: Input waveforms have $t_r \leq 2.0$ ns from 0.8 V to 2.0 V.

18421A-061

Figure 58. Drive Levels and Measurement Points



C_L includes all parasitic capacitances.

Figure 59. AC Test Load

18421A-062

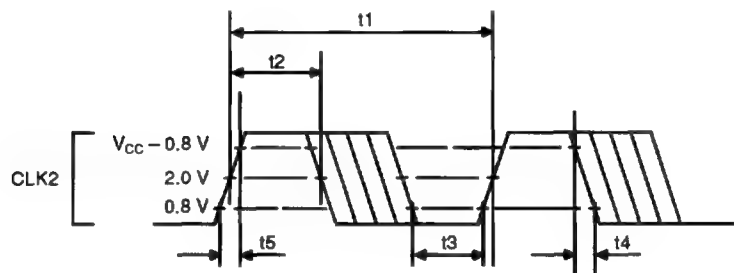


Figure 60. CLK2 Timing

18421A-063

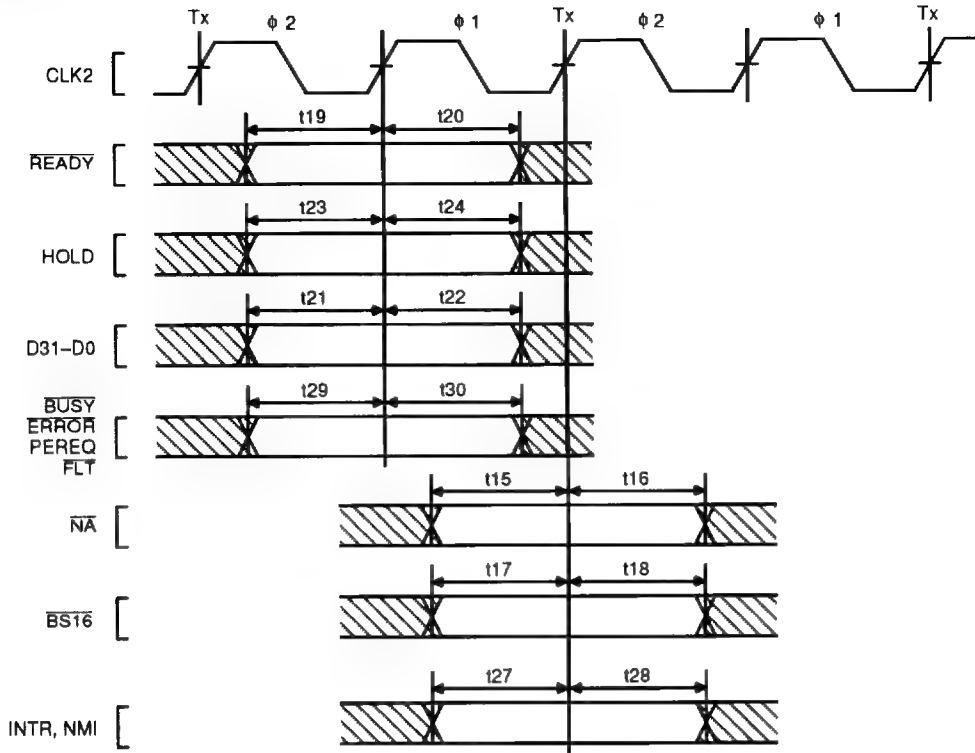


Figure 61. Input Setup and Hold Timing

18421A-064

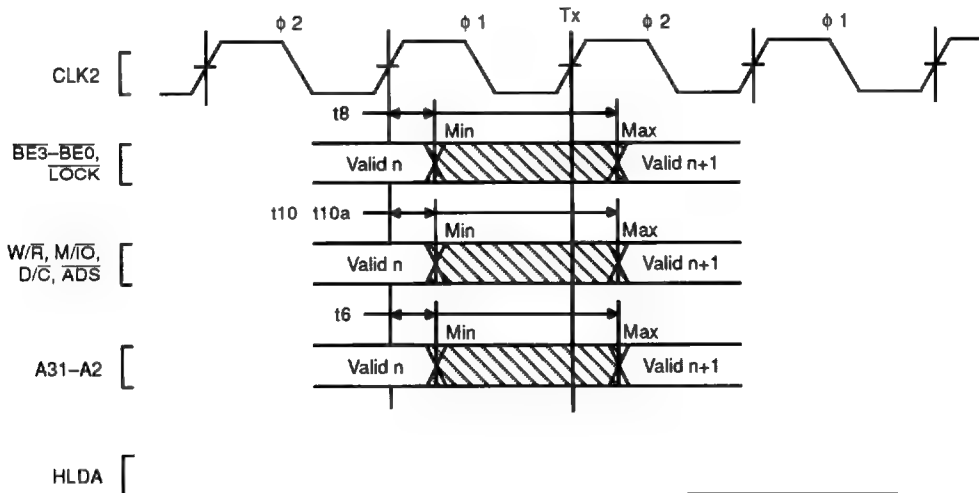


Figure 62. Output Valid Delay Timing

18421A-065

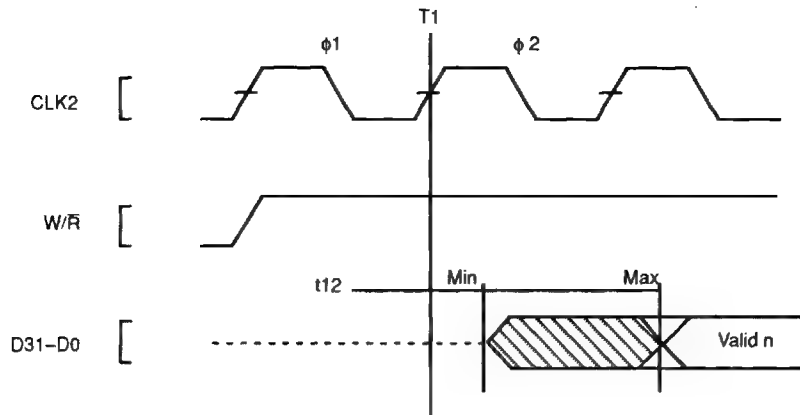


Figure 63. Write Data Valid Delay Timing (33 MHz)

18421A-066

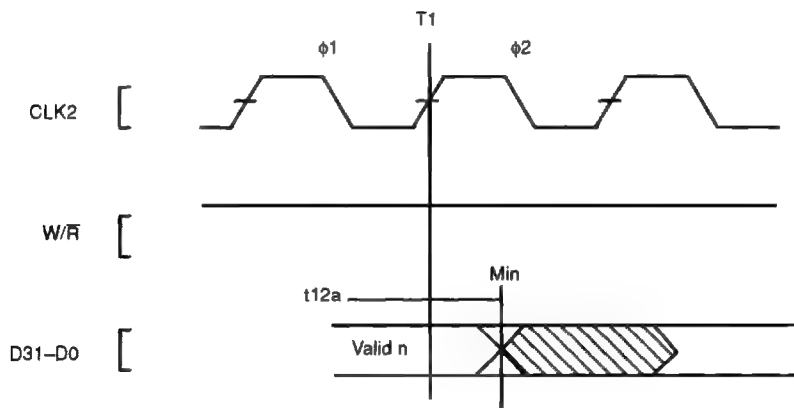
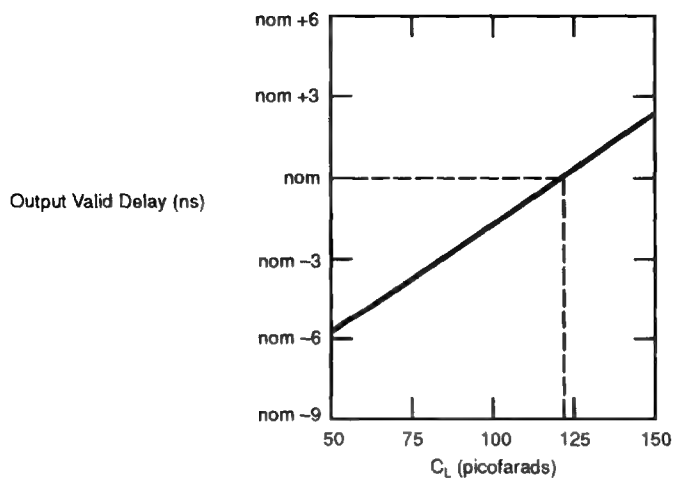


Figure 64. Write Data Hold Timing (33 MHz)

18421A-067

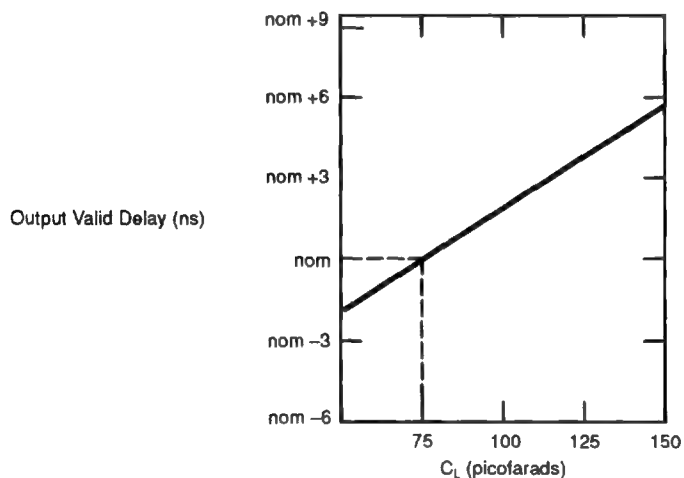


Note:

This graph will not be linear outside of the C_L range shown.

18421A-068

Figure 65. Typical Output Valid Delay Versus Load Capacitance at Maximum Operating Temperature ($C_L = 120$ pF)

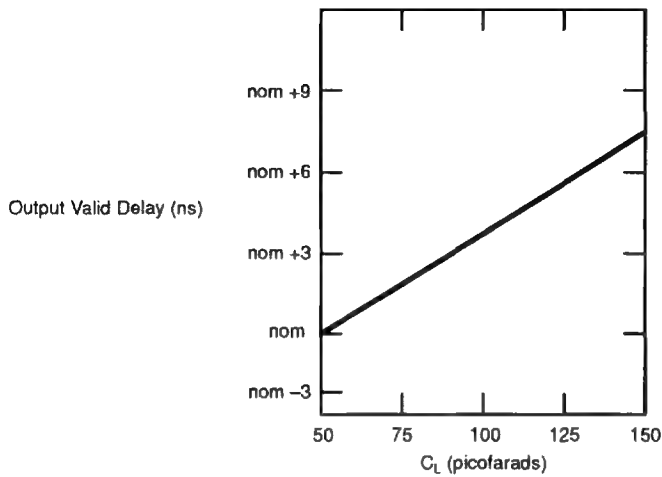


Note:

This graph will not be linear outside of the C_L range shown.

18421A-069

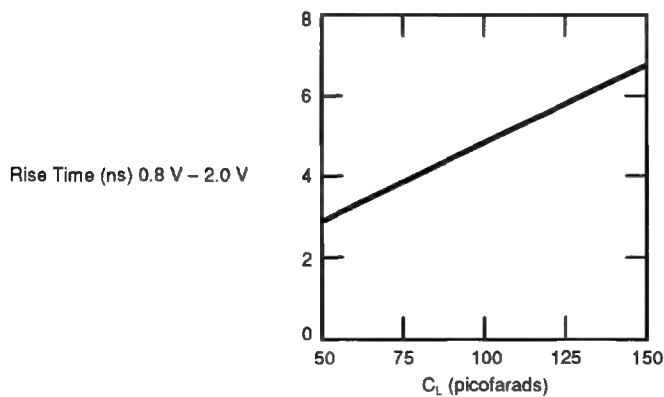
Figure 66. Typical Output Valid Delay Versus Load Capacitance at Maximum Operating Temperature ($C_L = 75$ pF)

**Note:**

This graph will not be linear outside of the C_L range shown.

18421A-070

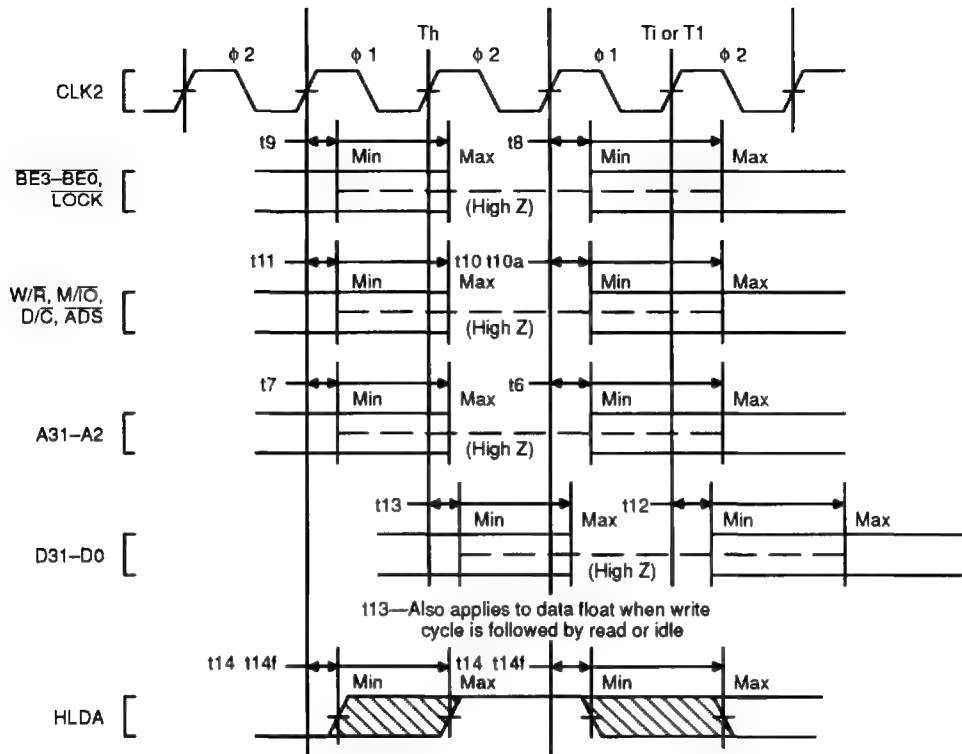
Figure 67. Typical Output Valid Delay Versus Load Capacitance at Maximum Operating Temperature ($C_L = 50$ pF)

**Note:**

This graph will not be linear outside of the C_L range shown.

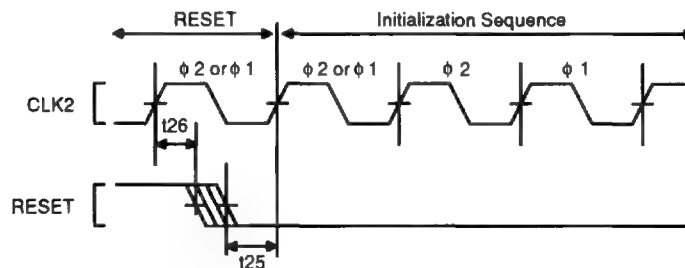
18421A-071

Figure 68. Typical Output Rise Time Versus Load Capacitance at Maximum Operating Temperature ($C_L = 50$ pF)



18421A-072

Figure 69. Output Float Delay and HLDA Valid Delay Timing



Note:

The second internal processor phase following RESET High-to-Low transition (provided t_{25} and t_{26} are met) is $\phi 2$.

18421A-073

Figure 70. RESET Setup and Hold Timing and Internal Phase

INSTRUCTION SET

This section describes the Am386DE microprocessor instruction set. A table lists all instructions along with instruction encoding diagrams and clock counts. Further details of the instruction encoding are then provided in the following sections, which completely describe the encoding structure and the definition of all fields occurring within Am386DE CPU instructions.

Am386DE Microprocessor Instruction Encoding and Clock Count Summary

To calculate elapsed time for an instruction, multiply the instruction clock count, as listed in Table 24, by the processor clock period (e.g., 30 ns for a 33-MHz Am386DE microprocessor).

For more detailed information on the encodings of instructions refer to the Instruction Encodings section on page 112. This section explains the general structure of instruction encodings and defines exactly the encodings of all fields contained within the instruction.

Instruction Clock Count Assumptions

1. The instruction has been prefetched and decoded, and is ready for execution.
2. Bus cycles do not require wait states.

3. There are no local bus HOLD requests delaying processor access to the bus.
4. No Exceptions are detected during instruction execution.
5. If an effective address is calculated, it does not use two general register components. One register, scaling, and displacement can be used within the clock counts shown. However, if the effective address calculation uses two general register components, add 1 clock to the clock count shown.

Instruction Clock Count Notation

1. If two clock counts are given, the smaller refers to a register operand and the larger refers to a memory operand.
2. n = number of times repeated.
3. m = number of components in the next instruction executed, where the entire displacement (if any) counts as one component; the entire immediate data (if any) counts as one component; and each of the other bytes of the instruction and prefix(es) each count as one component.

Table 24. Am386DE Microprocessor Instruction Set Summary

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
GENERAL DATA TRANSFER					
MOV = Move					
Register to Register/Memory	1 0 0 0 1 0 0 w mod reg r/m	2/2	2/2	b	h
Register/Memory to Register	1 0 0 0 1 0 1 w mod reg r/m	2/4	2/4	b	h
Immediate to Register/Memory	1 1 0 0 0 1 1 w mod 0 0 0 r/m immediate data	2/2	2/2	b	h
Immediate to Register (short form)	1 0 1 1 w reg immediate data	2	2		
Memory to Accumulator (short form)	1 0 1 0 0 0 0 w full displacement	4	4	b	h
Accumulator to Memory (short form)	1 0 1 0 0 0 1 w full displacement	2	2	b	h
Register/Memory to Segment Register	1 0 0 0 1 1 1 0 mod sreg3 r/m	2/5	18, 19	b	h, i, j
Segment Register to Register/Memory	1 0 0 0 1 1 0 0 mod reg r/m	2/2	2/2	b	h
MOVSB = Move with Sign Extension					
Register from Register/Memory	0 0 0 0 1 1 1 1 1 0 1 1 1 1 w mod reg r/m	3/6	3/6	b	h
MOVZX = Move with Zero Extension					
Register from Register/Memory	0 0 0 0 1 1 1 1 1 0 1 1 0 1 w mod reg r/m	3/6	3/6	b	h
PUSH = Push					
Register/Memory	1 1 1 1 1 1 1 1 mod 1 1 0 r/m	5	5	b	h
Register (short form)	0 1 0 1 0 reg	2	2	b	h
Segment Register (ES, CS, SS, or DS)	0 0 0 sreg 2 1 1 0	2	2	b	h
Segment Register (FS or GS)	0 0 0 0 1 1 1 1 1 0 sreg 3 0 0 0	2	2	b	h
Immediate	0 1 1 0 1 0 s 0 immediate data	2	2	b	h
PUSHA = Push All	0 1 1 0 0 0 0 0	18	18	b	h
POP = Pop					
Register/Memory	1 0 0 0 1 1 1 1 mod 0 0 0 r/m	5	5	b	h
Register (short form)	0 1 0 1 1 reg	4	4	b	h
Segment Register (ES, SS, or DS)	0 0 0 sreg 2 1 1 1	7	21	b	h, i, j
Segment Register (FS or GS)	0 0 0 0 1 1 1 1 1 0 sreg 3 0 0 1	7	21	b	h, i, j
POPA = Pop All	0 1 1 0 0 0 0 1	24	24	b	h
XCHG = Exchange					
Register/Memory with Register	1 0 0 0 0 1 1 w mod reg r/m	3/5	3/5	b, f	f, h
Register with Accumulator (short form)	1 0 0 1 0 reg	3	3		
IN = Input from:					
Fixed Port	1 1 1 0 0 1 0 w port number	12	6*/26**		m
Variable Port	1 1 1 0 1 1 0 w	13	7*/27**		m
OUT = Output to:					
Fixed Port	1 1 1 0 0 1 1 w port number	10	4*/24**		m
Variable Port	1 1 1 0 1 1 1 w	11	5*/25**		m
LEA = Load EA to Register	1 0 0 0 1 1 0 1 mod reg r/m	2	2		

* If CPL ≤ IOPL ** If CPL > IOPL

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
SEGMENT CONTROL					
LDS = Load pointer to DS	11000101 mod reg r/m	7	22	b	h, i, j
LES = Load pointer to ES	11000100 mod reg r/m	7	22	b	h, i, j
LFS = Load pointer to FS	00001111 10110100 mod reg r/m	7	25	b	h, i, j
LGS = Load pointer to GS	00001111 10110101 mod reg r/m	7	25	b	h, i, j
LSS = Load pointer to SS	00001111 10110010 mod reg r/m	7	22	b	h, i, j
FLAG CONTROL					
CLC = Clear Carry Flag	11111000	2	2		
CLD = Clear Direction Flag	11111100	2	2		
CLI = Clear Interrupt Enable Flag	11111010	8	8		m
CLTS = Clear Task Switched Flag	00001111 00000110	6	6	c	i
CMC = Complement Carry Flag	11110101	2	2		
LAHF = Load AH into Flag	10011111	2	2		
POPF = Pop Flag	10011101	5	5	b	h, n
PUSHF = Push Flag	10011100	4	4	b	h
SAHF = Store AH into Flag	10011110	3	3		
STC = Set Carry Flag	11111001	2	2		
STD = Set Direction Flag	11111101	2	2		
STI = Set Interrupt Enable Flag	11111011	8	8		m
ARITHMETIC					
ADD = Add					
Register to Register	000000dw mod reg r/m	2	2		
Register to Memory	0000000w mod reg r/m	7	7	b	h
Memory to Register	0000001w mod reg r/m	6	6	b	h
Immediate to Register/Memory	100000sw mod 000 r/m	2/7	2/7	b	h
Immediate to Accumulator (short form)	0000010w immediate data	2	2		
ADC = Add with carry					
Register to Register	000100dw mod reg r/m	2	2		
Register to Memory	0001000w mod reg r/m	7	7	b	h
Memory to Register	0001001w mod reg r/m	6	6	b	h
Immediate to Register/Memory	100000sw mod 010 r/m	2/7	2/7	b	h
Immediate to Accumulator (short form)	0001010w immediate data	2	2		
INC = Increment					
Register/Memory	1111111w mod 000 r/m	2/6	2/6	b	h
Register (short form)	01000 reg	2	2		
SUB = Subtract					
Register from Register	001010dw mod reg r/m	2	2		
Register from Memory	0010100w mod reg r/m	7	7	b	h
Memory from Register	0010101w mod reg r/m	6	6	b	h

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments				
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode			
ARITHMETIC (continued)								
Immediate from Register/Memory	<table><tr><td>0 0 1 0 0 1 1 w</td><td>mod 1 0 1 r/m</td></tr></table> immediate data	0 0 1 0 0 1 1 w	mod 1 0 1 r/m	2/ 7	2/ 7	b	h	
0 0 1 0 0 1 1 w	mod 1 0 1 r/m							
Immediate from Accumulator (short form)	<table><tr><td>0 0 0 1 1 1 0 w</td><td>immediate data</td></tr></table>	0 0 0 1 1 1 0 w	immediate data	2	2			
0 0 0 1 1 1 0 w	immediate data							
SBB = Subtract with Borrow								
Register from Register	<table><tr><td>0 0 0 1 1 0 d w</td><td>mod reg r/m</td></tr></table>	0 0 0 1 1 0 d w	mod reg r/m	2	2			
0 0 0 1 1 0 d w	mod reg r/m							
Register from Memory	<table><tr><td>0 0 0 1 1 0 0 w</td><td>mod reg r/m</td></tr></table>	0 0 0 1 1 0 0 w	mod reg r/m	7	7	b	h	
0 0 0 1 1 0 0 w	mod reg r/m							
Memory from Register	<table><tr><td>0 0 0 1 1 0 1 w</td><td>mod reg r/m</td></tr></table>	0 0 0 1 1 0 1 w	mod reg r/m	6	6	b	h	
0 0 0 1 1 0 1 w	mod reg r/m							
Immediate from Register/Memory	<table><tr><td>1 0 0 0 0 0 s w</td><td>mod 0 1 1 r/m</td></tr></table> immediate data	1 0 0 0 0 0 s w	mod 0 1 1 r/m	2/7	2/7	b	h	
1 0 0 0 0 0 s w	mod 0 1 1 r/m							
Immediate from Accumulator	<table><tr><td>0 0 0 1 1 1 0 w</td><td>immediate data</td></tr></table>	0 0 0 1 1 1 0 w	immediate data	2	2			
0 0 0 1 1 1 0 w	immediate data							
DEC = Decrement								
Register/Memory	<table><tr><td>1 1 1 1 1 1 1 w</td><td>reg 0 0 1 r/m</td></tr></table>	1 1 1 1 1 1 1 w	reg 0 0 1 r/m	2/6	2/6	b	h	
1 1 1 1 1 1 1 w	reg 0 0 1 r/m							
Register (short form)	<table><tr><td>0 1 0 0 1 reg</td><td></td></tr></table>	0 1 0 0 1 reg		2	2			
0 1 0 0 1 reg								
CMP = Compare								
Register with Register	<table><tr><td>0 0 1 1 1 0 d w</td><td>mod reg r/m</td></tr></table>	0 0 1 1 1 0 d w	mod reg r/m	2	2			
0 0 1 1 1 0 d w	mod reg r/m							
Memory with Register	<table><tr><td>0 0 1 1 1 0 0 w</td><td>mod reg r/m</td></tr></table>	0 0 1 1 1 0 0 w	mod reg r/m	5	5	b	h	
0 0 1 1 1 0 0 w	mod reg r/m							
Register with Memory	<table><tr><td>0 0 1 1 1 0 1 w</td><td>mod reg r/m</td></tr></table>	0 0 1 1 1 0 1 w	mod reg r/m	6	6	b	h	
0 0 1 1 1 0 1 w	mod reg r/m							
Immediate with Register/Memory	<table><tr><td>1 0 0 0 0 0 s w</td><td>mod 1 1 1 r/m</td></tr></table> immediate data	1 0 0 0 0 0 s w	mod 1 1 1 r/m	2/5	2/5	b	h	
1 0 0 0 0 0 s w	mod 1 1 1 r/m							
Immediate with Accumulator(short form)	<table><tr><td>0 0 1 1 1 1 0 w</td><td>immediate data</td></tr></table>	0 0 1 1 1 1 0 w	immediate data	2	2			
0 0 1 1 1 1 0 w	immediate data							
NEG = Change Sign	<table><tr><td>1 1 1 1 0 1 1 w</td><td>mod 0 1 1 r/m</td></tr></table>	1 1 1 1 0 1 1 w	mod 0 1 1 r/m	2/6	2/6	b	h	
1 1 1 1 0 1 1 w	mod 0 1 1 r/m							
AAA = ASCII Adjust for Add	<table><tr><td>0 0 1 1 0 1 1 1</td><td></td></tr></table>	0 0 1 1 0 1 1 1		4	4			
0 0 1 1 0 1 1 1								
DAA = Decimal Adjust for Add	<table><tr><td>0 0 1 1 1 1 1 1</td><td></td></tr></table>	0 0 1 1 1 1 1 1		4	4			
0 0 1 1 1 1 1 1								
AAS = ASCII Adjust for Subtract	<table><tr><td>0 0 1 0 0 1 1 1</td><td></td></tr></table>	0 0 1 0 0 1 1 1		4	4			
0 0 1 0 0 1 1 1								
DAS = Decimal Adjust for Subtract	<table><tr><td>0 0 1 0 1 1 1 1</td><td></td></tr></table>	0 0 1 0 1 1 1 1		4	4			
0 0 1 0 1 1 1 1								
MUL = Multiply (Unsigned)								
Accumulator with Register/Memory	<table><tr><td>1 1 1 1 0 1 1 w</td><td>mod 1 0 0 r/m</td></tr></table>	1 1 1 1 0 1 1 w	mod 1 0 0 r/m					
1 1 1 1 0 1 1 w	mod 1 0 0 r/m							
Multiplier -Byte		12-17/15-20	12-17/15-20	b,d	d,h			
-Word		12-25/15-28	12-25/15-28	b,d	d,h			
-Doubleword		12-41/15-44	12-41/15-44	b,d	d,h			
IMUL = Integer Multiply (signed)								
Accumulator with Register/Memory	<table><tr><td>1 1 1 1 0 1 1 w</td><td>mod 1 0 1 r/m</td></tr></table>	1 1 1 1 0 1 1 w	mod 1 0 1 r/m					
1 1 1 1 0 1 1 w	mod 1 0 1 r/m							
Multiplier -Byte		12-17/15-20	12-17/15-20	b,d	d,h			
-Word		12-25/15-28	12-25/15-28	b,d	d,h			
-Doubleword		12-41/15-44	12-41/15-44	b,d	d,h			
Register with Register/Memory	<table><tr><td>0 0 0 0 1 1 1 1</td><td>1 0 1 0 1 1 1 1</td><td>mod reg r/m</td></tr></table>	0 0 0 0 1 1 1 1	1 0 1 0 1 1 1 1	mod reg r/m				
0 0 0 0 1 1 1 1	1 0 1 0 1 1 1 1	mod reg r/m						
Multiplier -Byte		12-17/15-20	12-17/15-20	b,d	d,h			
-Word		12-25/15-28	12-25/15-28	b,d	d,h			
-Doubleword		12-41/15-44	12-41/15-44	b,d	d,h			
Register/Memory with Immediate to Register	<table><tr><td>0 1 1 0 1 0 s 1</td><td>mod reg r/m</td></tr></table> immediate data	0 1 1 0 1 0 s 1	mod reg r/m					
0 1 1 0 1 0 s 1	mod reg r/m							
-Word		13-26/14-27	13-26/14-27	b,d	d,h			
-Doubleword		13-42/14-43	13-42/14-43	b,d	d,h			

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
ARITHMETIC (continued)					
DIV = Divide (Unsigned)					
Accumulator by Register/Memory	1111011w mod 110 r/m				
Divisor -Byte		14/17	14/17	b,e	e,h
-Word		22/25	22/25	b,e	e,h
-Doubleword		38/41	38/41	b,e	e,h
IDIV = Integer Divide (Signed)					
Accumulator by Register/Memory	11110112 mod 111 r/m				
Divisor -Byte		19/22	19/22	b,e	e,h
-Word		27/30	27/30	b,e	e,h
-Doubleword		43/46	43/46	b,e	e,h
AAD = ASCII Adjust for Divide	11010101 00001010	19	19		
AAM = ASCII Adjust for Multiply	11010100 00001010	17	17		
CBW = Convert Byte to Word	10011000	3	3		
CWD = Convert Word to Double Word	10011001	2	2		
LOGIC					
Shift/Rotate Instructions					
Not Through Carry (ROL, ROR, SAL, SAR, SHL, and SHR)					
Register/Memory by 1	1101000w mod TTT r/m	3/7	3/7	b	h
Register/Memory by CL	1101001w mod TTT r/m	3/7	3/7	b	h
Register Memory by Immediate Count	1100000w mod TTT r/m	3/7	3/7	b	h
Through Carry (RCL and RCR)					
Register/Memory by 1	1101000w mod TTT r/m	9/10	9/10	b	h
Register/Memory by CL	1101001w mod TTT r/m	9/10	9/10	b	h
Register/Memory by Immediate Count	1100000w mod TTT r/m	9/10	9/10	b	h
TTT Instruction					
000	ROL				
001	ROR				
010	RCL				
011	RCR				
100	SHL/SAL				
101	SHR				
111	SAR				
SHLD = Shift Left Double					
Register/Memory by Immediate	00001111 10100100 mod reg r/m	3/7	3/7		
Register/Memory by CL	00001111 10100101 mod reg r/m	3/7	3/7		
SHRD = Shift Right Double					
Register/Memory by Immediate	00001111 10101100 mod reg r/m	3/7	3/7		
Register/Memory by CL	00001111 10101101 mod reg r/m	3/7	3/7		
AND = And					
Register to Register	0010000w mod reg r/m	2	2		
Register to Memory	0010000w mod reg r/m	7	7	b	h
Memory to Register	0010001w mod reg r/m	6	6	b	h
Immediate to Register/Memory	1000000w mod 110 r/m	2/7	2/7	b	h
Immediate to Accumulator (short form)	0010010w	2	2		
TEST = And Function to Flags, no Result					
Register/Memory and Register	1000010w mod reg r/m	2/5	2/5	b	h
Immediate Data and Register/Memory	1111011w mod 000 r/m	2/5	2/5	b	h
Immediate Data and Accumulator (short form)	1010100w	2	2		

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

				Clock Count		Comments	
Instruction	Format		Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode	
LOGIC (continued)							
OR = Or							
Register to Register	000010dw	mod reg r/m	2	2			
Register to Memory	0000100w	mod reg r/m	7	7	b	h	
Memory to Register	0000101w	mod reg r/m	6	6	b	h	
Immediate and Register/Memory	1000000w	mod 001 r/m	2/7	2/7	b	h	
Immediate to Accumulator (short form)	0000110w	immediate data	2	2			
XOR = Exclusive or							
Register to Register	001100dw	mod reg r/m	2	2			
Register to Memory	0011000w	mod reg r/m	7	7	b	h	
Memory to Register	0011001w	mod reg r/m	6	6	b	h	
Immediate to Register/Memory	1000000w	mod 110 r/m	2/7	2/7	b	h	
Immediate to Accumulator (short form)	0011010w	immediate data	2	2			
NOT = Invert Register/Memory	1111011w	mod 010 r/m	2/6	2/6	b	h	
STRING MANIPULATION							
CMPS = Compare Byte/Word	1010011w		10	10	b	h	
INS = Input Byte/Wd from DX Port	0110110w		15	9*/29**	b	h, m	
LODS = Load Byte/Wd to AL/AX	1010110w		5	5	b	h	
MOVS = Move Byte/Word	1010010w		8	8	b	h	
OUTS = Output Byte/Wd to DX Port	0110111w		14	8*/28**	b	h, m	
SCAS = Scan Byte/Word	1010111w		8	8	b	h	
STOS = Store Byte/Word from AL/AX/EX	1010101w		5	5	b	h	
XLAT = Translate String	11010111		5	5		h	
REPEATED STRING MANIPULATION Repeated by Count in CX or ECX							
REPE CMPS = Compare string (Find Non-Match)	11110011	1010011w	5+9n	5+9n	b	h	
REPNE CMPS = Compare String (Find Match)	11110010	1010011w	5+9n	5+9n	b	h	
REP INS = Input String	11110010	0110110w	14 + 6n	8 + 6n*/ 28 + 6n**	b	h, m	
REP LODS = Load String	11110010	1010110w	5 + 6n	5 + 6n	b	h	
REP MOVS = Move String	11110010	1010010w	8 + 4n	8 + 4n	b	h	
REP OUTS = Output String	11110010	0110111w	12 + 5n	6 + 5n*/ 26 + 5n**	b	h, m	
REPE SCAS = Scan String (Find Non-AL/AX/EAX)	11110011	1010111w	5 + 8n	5 + 8n	b	h	
REPNE SCAS = Store String (Find AL/AX/EAX)	11110010	1010111w	5 + 8n	5 + 9n	b	h	
REP STOS = Store String	11110010	1010101w	5+5n	5+5n	b	h	
BIT MANIPULATION							
BSF = Scan Bt Forward	00001111	10111100 mod reg r/m	11 + 3n	11 + 3n	b	h	
BSR = Scan Bt Reverse	00001111	10111101 mod reg r/m	9 + 3n	9 + 3n	b	h	

* If CPL ≤ IOPL

** If CPL > IOPL

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments				
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode			
BIT MANIPULATION (continued)								
BT = Test Bit								
Register/Memory, Immediate	<table><tr><td>00001111</td><td>10111010</td><td>mod 100 r/m</td></tr></table> immediate 8-bit data	00001111	10111010	mod 100 r/m	3/6	3/6	b	h
00001111	10111010	mod 100 r/m						
Register/Memory, Register	<table><tr><td>00001111</td><td>10100011</td><td>mod reg r/m</td></tr></table>	00001111	10100011	mod reg r/m	3/12	3/12	b	h
00001111	10100011	mod reg r/m						
BTC = Test Bit and Complement								
Register/Memory, Immediate	<table><tr><td>00001111</td><td>10111010</td><td>mod 111 r/m</td></tr></table> immediate 8-bit data	00001111	10111010	mod 111 r/m	6/8	6/8	b	h
00001111	10111010	mod 111 r/m						
Register/Memory, Register	<table><tr><td>00001111</td><td>10111011</td><td>mod reg r/m</td></tr></table>	00001111	10111011	mod reg r/m	6/13	6/13	b	h
00001111	10111011	mod reg r/m						
BTR = Test Bit and Reset								
Register/Memory, Immediate	<table><tr><td>00001111</td><td>10111010</td><td>mod 110 r/m</td></tr></table> immediate 8-bit data	00001111	10111010	mod 110 r/m	6/8	6/8	b	h
00001111	10111010	mod 110 r/m						
Register/Memory, Register	<table><tr><td>00001111</td><td>10110011</td><td>mod reg r/m</td></tr></table>	00001111	10110011	mod reg r/m	6/13	6/13	b	h
00001111	10110011	mod reg r/m						
BTS = Test Bit and Set								
Register/Memory, Immediate	<table><tr><td>00001111</td><td>10111010</td><td>mod 101 r/m</td></tr></table> immediate 8-bit data	00001111	10111010	mod 101 r/m	6/8	6/8	b	h
00001111	10111010	mod 101 r/m						
Register/Memory, Register	<table><tr><td>00001111</td><td>10101011</td><td>mod reg r/m</td></tr></table>	00001111	10101011	mod reg r/m	6/13	6/13	b	h
00001111	10101011	mod reg r/m						
CONTROL TRANSFER								
CALL = Call								
Direct Within Segment	<table><tr><td>11101000</td><td>full displacement</td></tr></table>	11101000	full displacement	7 + m	7 + m	b	r	
11101000	full displacement							
Register/Memory Indirect Within Segment	<table><tr><td>11111111</td><td>mod 010 r/m</td></tr></table>	11111111	mod 010 r/m	7 + m 10 + m	7 + m 10 + m	b	h, r	
11111111	mod 010 r/m							
Direct Intersegment	<table><tr><td>10011010</td><td>unsigned full offset, selector</td></tr></table>	10011010	unsigned full offset, selector	17 + m	34 + m	b	j, k, r	
10011010	unsigned full offset, selector							
Protected Mode Only (Direct Intersegment)								
Via Call Gate to Same Privilege Level			52 + m		h, j, k, r			
Via Call Gate to Different Privilege Level, (No Parameters)			86 + m		h, j, k, r			
Via Call Gate to Different Privilege Level, (x Parameters)			94+4x+m		h, j, k, r			
From 80286 Task to 80286 TSS			273		h, j, k, r			
From 80286 Task to Am386DE CPU TSS			298		h, j, k, r			
From Am386DE CPU Task to 80286 TSS			273		h, j, k, r			
From Am386DE CPU Task to Am386DE CPU TSS			300		h, j, k, r			
Indirect Intersegment	<table><tr><td>11111111</td><td>mod 011 r/m</td></tr></table>	11111111	mod 011 r/m	22 + m	38 + m	b	h, j, k, r	
11111111	mod 011 r/m							
Protected Mode Only (Indirect Intersegment)								
Via Call Gate to Same Privilege Level			56 + m		h, j, k, r			
Via Call Gate to Different Privilege Level (No Parameters)			90 + m		h, j, k, r			
Via Call Gate to Different Privilege Level (x Parameters)			98+4x+m		h, j, k, r			
From 80286 Task to 80286 TSS			278		h, j, k, r			
From 80286 Task to Am386DE CPU TSS			303		h, j, k, r			
From Am386DE CPU Task to 80286 TSS			278		h, j, k, r			
From Am386DE CPU Task to Am386DE CPU TSS			305		h, j, k, r			
JMP = Unconditional Jump								
Short	<table><tr><td>11101011</td><td>8-bit displacement</td></tr></table>	11101011	8-bit displacement	7 + m	7 + m		r	
11101011	8-bit displacement							
Direct within Segment	<table><tr><td>11101001</td><td>full displacement</td></tr></table>	11101001	full displacement	7 + m	7 + m		r	
11101001	full displacement							
Register/Memory Indirect within Segment	<table><tr><td>11111111</td><td>mod 100 r/m</td></tr></table>	11111111	mod 100 r/m	7 + m 10 + m	7 + m 10 + m	b	h, r	
11111111	mod 100 r/m							
Direct Intersegment	<table><tr><td>11101010</td><td>unsigned full offset, selector</td></tr></table>	11101010	unsigned full offset, selector	12 + m	27 + m		j, k, r	
11101010	unsigned full offset, selector							

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
CONTROL TRANSFER (continued)					
Protected Mode Only (Direct Intersegment) Via Call Gate to Same Privilege Level From 80286 Task to 80286 TSS From 80286 Task to Am386DE CPU TSS From Am386DE CPU Task to 80286 TSS From Am386DE CPU Task to Am386DE CPU TSS			45 + m 274 301 270 303		h, j, k, r h, j, k, r h, j, k, r h, j, k, r h, j, k, r
Indirect Intersegment	11111111 mod 101 r/m	17 + m	31 + m	b	h, j, k, r
Protected Mode Only (Indirect Intersegment) Via Call Gate to Same Privilege Level From 80286 Task to 80286 TSS From 80286 Task to Am386DE CPU TSS From Am386DE CPU Task to 80286 TSS From Am386DE CPU Task to Am386DE CPU TSS			49 + m 279 306 275 308		h, j, k, r h, j, k, r h, j, k, r h, j, k, r h, j, k, r
RET = Return from CALL					
Within Segment	11000011	10 + m	10 + m	b	g, h, r
Within Seg. Adding Immediate to SP	11000010 16-bit displacement	10 + m	10 + m	b	g, h, r
Intersegment	11001011	18 + m	32 + m	b	g, h, j, k, r
Intersegment Adding Immediate to SP	11001010 16-bit displacement	18 + m	32 + m	b	g, h, j, k, r
Protected Mode Only (RET) to Different Privilege Level Intersegment Intersegment Adding Immediate to SP			69 69		h, j, k, r h, j, k, r
CONDITIONAL JUMPS (Note: Times are Jump "Taken or Not Taken")					
JO = Jump on Overflow					
8-bit Displacement	01110000 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000000 full displacement	7+m or 3	7+m or 3		r
JNO = Jump on Not Overflow					
8-bit Displacement	01110001 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000001 full displacement	7+m or 3	7+m or 3		r
JB/JNAE = Jump on Below/Not Above or Equal					
8-bit Displacement	01110010 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000010 full displacement	7+m or 3	7+m or 3		r
JNB/JAE = Jump on Not Below/Above or Equal					
8-bit Displacement	01110011 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000011 full displacement	7+m or 3	7+m or 3		r
JE/JZ = Jump on Equal/ Zero					
8-bit Displacement	01110100 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000100 full displacement	7+m or 3	7+m or 3		r
JNE/JNZ = Jump on Not Equal/Not Zero					
8-bit Displacement	01110101 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000101 full displacement	7+m or 3	7+m or 3		r
JBE/JNA = Jump on Below or Equal/Not Above					
8-bit Displacement	01110110 8-bit displacement	7+m or 3	7+m or 3		r
Full Displacement	00001111 10000110 full displacement	7+m or 3	7+m or 3		r

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

				Clock Count		Comments	
Instruction	Format			Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
CONDITIONAL JUMPS (continued)							
JNBE/JA = Jump on Not Below or Equal/Above							
8-bit Displacement	0 1 1 1 0 1 1 1	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 1 1 1	full displacement	7+m or 3	7+m or 3		r
JS = Jump on Sign							
8-bit Displacement	0 1 1 1 1 0 0 0	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 0 0 0	full displacement	7+m or 3	7+m or 3		r
JNS = Jump on Not Sign							
8-bit Displacement	0 1 1 1 1 0 0 1	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 0 0 1	full displacement	7+m or 3	7+m or 3		r
JP/JPE = Jump on Parity/Parity Even							
8-bit Displacement	0 1 1 1 1 0 1 0	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 0 1 0	full displacement	7+m or 3	7+m or 3		r
JNP/JPO = Jump on Not Parity/Parity Odd							
8-bit Displacement	0 1 1 1 1 0 1 1	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 0 1 1	full displacement	7+m or 3	7+m or 3		r
JL/JNGE = Jump on Less/Not Greater or Equal							
8-bit Displacement	0 1 1 1 1 1 0 0	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 1 0 0	full displacement	7+m or 3	7+m or 3		r
JNL/JGE = Jump on Not Less/Greater or Equal							
8-bit Displacement	0 1 1 1 1 1 0 1	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 1 0 1	full displacement	7+m or 3	7+m or 3		r
JLE/JNG = Jump on Less or Equal/Not Greater							
8-bit Displacement	0 1 1 1 1 1 1 0	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 1 1 0	full displacement	7+m or 3	7+m or 3		r
JNLE/JG = Jump on Not Less or Equal/Greater							
8-bit Displacement	0 1 1 1 1 1 1 1	8-bit displacement		7+m or 3	7+m or 3		r
Full Displacement	0 0 0 0 1 1 1 1	1 0 0 0 1 1 1 1	full displacement	7+m or 3	7+m or 3		r
JCXZ = Jump on CX Zero *							
	1 1 1 0 0 0 1 1	8-bit displacement		9+m or 5	9+m or 5		r
JECXZ = Jump on ECX Zero *							
	1 1 1 0 0 0 1 1	8-bit displacement		9+m or 5	9+m or 5		r
LOOP = Loop CX Times							
	1 1 1 0 0 0 1 0	8-bit displacement		11 + m	11 + m		r
LOOPZ/LOOPE = Loop with Zero/Equal							
	1 1 1 0 0 0 0 1	8-bit displacement		11 + m	11 + m		r
LOOPNZ/LOOPNE = Loop while Not Zero							
	1 1 1 0 0 0 0 0	8-bit displacement		11 + m	11 + m		r
CONDITIONAL BYTE SET (Note: Times are Register/Memory)							
SETO = Set Byte on Overflow							
To Register/Memory	0 0 0 0 1 1 1 1	1 0 0 1 0 0 0 0	mod 0 0 0 r/m	4/5	4/5		h
SETNO = Set Byte on Not Overflow							
To Register/Memory	0 0 0 0 1 1 1 1	1 0 0 1 0 0 0 1	mod 0 0 0 r/m	4/5	4/5		h
SETB/SETNAE = Set Byte on Below/Not Above or Equal							
To Register/Memory	0 0 0 0 1 1 1 1	1 0 0 1 0 0 1 0	mod 0 0 0 r/m	4/5	4/5		h

* Address Size Prefix Differentiates JCXZ from JECXZ

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments				
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode			
CONDITIONAL BYTE SET (continued)								
SETNB = Set Byte on Not Below/Above or Equal								
To Register/Memory	<table><tr><td>00001111</td><td>10010011</td><td>mod 000 r/m</td></tr></table>	00001111	10010011	mod 000 r/m	4/5	4/5		h
00001111	10010011	mod 000 r/m						
SETE/SETZ = Set Byte on Equal/Zero								
To Register/Memory	<table><tr><td>00001111</td><td>10010100</td><td>mod 000 r/m</td></tr></table>	00001111	10010100	mod 000 r/m	4/5	4/5		h
00001111	10010100	mod 000 r/m						
SETNE/SETNZ = Set Byte on Not Equal/Not Zero								
To Register/Memory	<table><tr><td>00001111</td><td>10010101</td><td>mod 000 r/m</td></tr></table>	00001111	10010101	mod 000 r/m	4/5	4/5		h
00001111	10010101	mod 000 r/m						
SETBE/SETNA = Set Byte on Below or Equal/Not Above								
To Register/Memory	<table><tr><td>00001111</td><td>10010110</td><td>mod 000 r/m</td></tr></table>	00001111	10010110	mod 000 r/m	4/5	4/5		h
00001111	10010110	mod 000 r/m						
SETNBE/SETA = Set Byte on Not Below or Equal/Above								
To Register/Memory	<table><tr><td>00001111</td><td>10010111</td><td>mod 000 r/m</td></tr></table>	00001111	10010111	mod 000 r/m	4/5	4/5		h
00001111	10010111	mod 000 r/m						
SETS = Set Byte on Sign								
To Register/Memory	<table><tr><td>00001111</td><td>10011000</td><td>mod 000 r/m</td></tr></table>	00001111	10011000	mod 000 r/m	4/5	4/5		h
00001111	10011000	mod 000 r/m						
SETNS = Set Byte on Not Sign								
To Register/Memory	<table><tr><td>00001111</td><td>10011001</td><td>mod 000 r/m</td></tr></table>	00001111	10011001	mod 000 r/m	4/5	4/5		h
00001111	10011001	mod 000 r/m						
SETP/SETPE = Set Byte on Parity/Parity Even								
To Register/Memory	<table><tr><td>00001111</td><td>10011010</td><td>mod 000 r/m</td></tr></table>	00001111	10011010	mod 000 r/m	4/5	4/5		h
00001111	10011010	mod 000 r/m						
SETNP/SETPO = Set Byte on Not Parity/Parity Odd								
To Register/Memory	<table><tr><td>00001111</td><td>10011011</td><td>mod 000 r/m</td></tr></table>	00001111	10011011	mod 000 r/m	4/5	4/5		h
00001111	10011011	mod 000 r/m						
SETL/SETNGE = Set Byte on Less/Not Greater or Equal								
To Register/Memory	<table><tr><td>00001111</td><td>10011100</td><td>mod 000 r/m</td></tr></table>	00001111	10011100	mod 000 r/m	4/5	4/5		h
00001111	10011100	mod 000 r/m						
SETNL/SETGE = Set Byte on Not Less/Greater or Equal								
To Register/Memory	<table><tr><td>00001111</td><td>01111101</td><td>mod 000 r/m</td></tr></table>	00001111	01111101	mod 000 r/m	4/5	4/5		h
00001111	01111101	mod 000 r/m						
SETLE/SETNG = Set Byte on Less or Equal/Not Greater								
To Register/Memory	<table><tr><td>00001111</td><td>10011110</td><td>mod 000 r/m</td></tr></table>	00001111	10011110	mod 000 r/m	4/5	4/5		h
00001111	10011110	mod 000 r/m						
SETNLE/SETG = Set Byte on Not Less or Equal/Greater								
To Register/Memory	<table><tr><td>00001111</td><td>10011111</td><td>mod 000 r/m</td></tr></table>	00001111	10011111	mod 000 r/m	4/5	4/5		h
00001111	10011111	mod 000 r/m						
ENTER = Enter Procedure								
L = 0	<table><tr><td>11001000</td><td>16-bit displacement, 8-bit level</td></tr></table>	11001000	16-bit displacement, 8-bit level	10	10	b	h	
11001000	16-bit displacement, 8-bit level							
L = 1		12	12	b	h			
L > 1		15+4(n-1)	15+4(n-1)	b	h			
LEAVE = Leave Procedure								
	<table><tr><td>11001001</td></tr></table>	11001001	4	4	b	h		
11001001								
INTERRUPT INSTRUCTIONS								
INT = Interrupt:								
Type Specified	<table><tr><td>11001101</td><td>type</td></tr></table>	11001101	type	37		b		
11001101	type							
Type 3	<table><tr><td>11001100</td></tr></table>	11001100	33		b			
11001100								
INTO = Interrupt if Overflow Flag Set								
If OF = 1	<table><tr><td>11001110</td></tr></table>	11001110	35		b, e			
11001110								
If OF = 0		3	3	b, e				

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
INTERRUPT INSTRUCTIONS (continued)					
Bound = Interrupt 5 If Detect Value Out of Range	0 1 1 0 0 0 1 0 mod reg r/m				
If Out of Range		44		b, e	g, h, j, k, r
If in Range		10	10	b, e	g, h, j, k, r
Protected Mode Only (INT)					
INT: Type Specified					
Via Interrupt or Trap Gate to Same Privilege Level			59		g, j, k, r
Via Interrupt or Trap Gate to Different Privilege Level			99		g, j, k, r
From 80286 Task to 80286 TSS via Task Gate			282		g, j, k, r
From 80286 Task to Am386DE CPU TSS via Task Gate			309		g, j, k, r
From Am386DE CPU Task to 80286 TSS via Task Gate			284		g, j, k, r
From Am386DE CPU Task to Am386DE CPU TSS via Task Gate			311		g, j, k, r
INT: Type 3					
Via Interrupt or Trap Gate to Same Privilege Level			59		g, j, k, r
Via Interrupt or Trap Gate to Different Privilege Level			99		g, j, k, r
From 80286 Task to 80286 TSS via Task Gate			278		g, j, k, r
From 80286 Task to Am386DE CPU TSS via Task Gate			305		g, j, k, r
From Am386DE CPU Task to 80286 TSS via Task Gate			280		g, j, k, r
From Am386DE CPU Task to Am386DE CPU TSS via Task Gate			307		g, j, k, r
INTO					
Via Interrupt or Trap Gate to Same Privilege Level			59		g, j, k, r
Via Interrupt or Trap Gate to Different Privilege Level			99		g, j, k, r
From 80286 Task to 80286 TSS via Task Gate			280		g, j, k, r
From 80286 Task to Am386DE CPU TSS via Task Gate			307		g, j, k, r
From Am386DE CPU Task to 80286 TSS via Task Gate			282		g, j, k, r
From Am386DE CPU Task to Am386DE CPU TSS via Task Gate			309		g, j, k, r
BOUND					
Via Interrupt or Trap Gate to Same Privilege Level			59		g, j, k, r
Via Interrupt or Trap Gate to Different Privilege Level			99		g, j, k, r
From 80286 Task to 80286 TSS via Task Gate			254		g, j, k, r
From 80286 Task to Am386DE CPU TSS via Task Gate			284		g, j, k, r
From Am386DE CPU Task to 80286 TSS via Task Gate			264		g, j, k, r
From Am386DE CPU Task to Am386DE CPU TSS via Task Gate			294		g, j, k, r
INTERRUPT RETURN					
IRET = Interrupt Return	1 1 0 0 1 1 1 1	22			g, h, j, k, r
Protected Mode Only (IRET)					
To the Same Privilege Level (within Task)			38		g, h, j, k, r
To Different Privilege Level (within Task)			82		g, h, j, k, r
From 80286 Task to 80286 TSS			232		h, j, k, r
From 80286 Task to Am386DE CPU TSS			265		h, j, k, r
From Am386DE CPU Task to 80286 TSS			271		h, j, k, r
From Am386DE CPU Task to Am386DE CPU TSS			275		h, j, k, r

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments	
Instruction	Format	Real Address Mode	Protected Address Mode	Real Address Mode	Protected Address Mode
PROCESSOR CONTROL					
HLT = HALT	11110100	5	5		1
MOV = Move to and From Control/Debug/Test Registers					
CR0/CR2/CR3 from register	00001111 00100010 11eee reg	11/4/5	11/4/5		1
Register From CR3-m-0	00001111 00100000 11eee reg	6	6		1
DR3-0 From Register	00001111 00100011 11eee reg	22	22		1
DR7-6 From Register	00001111 00100011 11eee reg	16	16		1
Register from DR7-6	00001111 00100001 11eee reg	14	14		1
Register from DR3-0	00001111 00100001 11eee reg	22	22		1
TR7-6 from Register	00001111 00100110 11eee reg	12	12		1
Register from TR70 0001111	00100100 11eee reg	12		1	
NOP = No Operation	10010000	3	3		
WAIT = Wait until BUSY pin is negated	10011011	7	7		
NOP = No Operation	10010000	3	3		
PROCESSOR EXTENSION INSTRUCTIONS					
Processor Extension Escape	11011TTT mod LLL r/m				h
TTT and LLL bits are op-code information for coprocessor					
PREFIX BYTES					
Address Size Prefix	01100111	0	0		
LOCK = Bus Lock Prefix	11110000	0	0		m
Operand Size Prefix	01100110	0	0		
Segment Override Prefix					
CS:	00101110	0	0		
DS:	00111110	0	0		
ES:	00100110	0	0		
FS:	01100100	0	0		
GS:	01100101	0	0		
SS:	00110110	0	0		
PROTECTION CONTROL					
ARPL = Adjust Requested Privilege Level					
From Register/Memory	01100011 mod reg r/m	N/A	20/21	a	h
LAR = Load Access Rights					
From Register/Memory	00001111 00000010 mod reg r/m	N/A	15/16	a	g, h, j, p
LGDT = Load Global Descriptor					
Table Register	00001111 00000001 mod 010 r/m	11	11	b, c	h, l
LIDT = Load Interrupt Descriptor					
Table Register	00001111 00000001 mod 011 r/m	11	11	b, c	h, l
LLDT = Load Local Descriptor					
Table Register to Register/Memory	00001111 00000000 mod 010 r/m	N/A	20/24	a	g, h, j, l
LMSW = Load Machine Status Word					
From Register/Memory	00001111 00000001 mod 110 r/m	11/14	11/14	b, c	h,

Table 24. Am386DE Microprocessor Instruction Set Summary (continued)

		Clock Count		Comments				
Instruction	Format	Real Address Mode	Protected Virtual Address Mode	Real Address Mode	Protected Virtual Address Mode			
PROTECTION CONTROL (continued)								
LSL = Load Segment Limit								
From Register/Memory	<table><tr><td>00001111</td><td>00000011</td><td>mod reg r/m</td></tr></table>	00001111	00000011	mod reg r/m	N/A	21/22	a	g, h, j, p
00001111	00000011	mod reg r/m						
Byte-Granular Limit		N/A	25/26	a	g, h, j, p			
Page-Granular Limit								
LTR = Load Task Register								
From Register/Memory	<table><tr><td>00001111</td><td>00000000</td><td>mod 001 r/m</td></tr></table>	00001111	00000000	mod 001 r/m	N/A	23/27	a	g, h, j, l
00001111	00000000	mod 001 r/m						
SGDT = Store Global Descriptor								
Table Register	<table><tr><td>00001111</td><td>00000001</td><td>mod 000 r/m</td></tr></table>	00001111	00000001	mod 000 r/m	9	9	b, c	h
00001111	00000001	mod 000 r/m						
SIDT = Store Interrupt Descriptor								
Table Register	<table><tr><td>00001111</td><td>00000001</td><td>mod 001 r/m</td></tr></table>	00001111	00000001	mod 001 r/m	9	9	b, c	h
00001111	00000001	mod 001 r/m						
SLDT = Store Local Descriptor Table Register								
To Register/Memory	<table><tr><td>00001111</td><td>00000000</td><td>mod 000 r/m</td></tr></table>	00001111	00000000	mod 000 r/m	N/A	2/2	a	h
00001111	00000000	mod 000 r/m						
SMSW = Store Machine Status Word								
	<table><tr><td>00001111</td><td>00000001</td><td>mod 100 r/m</td></tr></table>	00001111	00000001	mod 100 r/m	2/2	2/2	b, c	h, l
00001111	00000001	mod 100 r/m						
STR = Store Task Register								
To Register/Memory	<table><tr><td>00001111</td><td>00000000</td><td>mod 001 r/m</td></tr></table>	00001111	00000000	mod 001 r/m	N/A	2/2	a	h
00001111	00000000	mod 001 r/m						
VERR = Verify Read Access								
Register/Memory	<table><tr><td>00001111</td><td>00000000</td><td>mod 100 r/m</td></tr></table>	00001111	00000000	mod 100 r/m	N/A	10/11	a	g, h, j, p
00001111	00000000	mod 100 r/m						
VERW = Verify Write Access								
	<table><tr><td>00001111</td><td>00000000</td><td>mod 101 r/m</td></tr></table>	00001111	00000000	mod 101 r/m	N/A	15/16	a	g, h, j, p
00001111	00000000	mod 101 r/m						

Instruction Notes for Table 23.

Notes a through c apply to Am386DE CPU Real Address Mode only.

- a. This is a Protected Mode instruction. Attempted execution in Real Mode will result in Exception 6 (Invalid op-code).
- b. Exception 13 fault (General Protection) will occur in Real Mode if an operand reference is made that partially or fully extends beyond the maximum CS, DS, ES, FS, or GS limit, FFFFH. Exception 12 (fault stack segment limit violation or not present) will occur in Real Mode if an operand reference is made that partially or fully extends beyond the maximum SS limit.
- c. This instruction may be executed in Real Mode. In Real Mode, its purpose is primarily to initialize the CPU for Protected Mode.

Notes d through g apply to Am386DE CPU Real Address Mode and Am386DE CPU Protected Address Mode.

- d. The Am386DE CPU uses an early-out multiply algorithm. The actual number of clocks depends on the position of the most significant bit in the operand (multiplier). Clock counts given are minimum to maximum. To calculate actual clocks, use the following formula: Actual Clock = if $m < 0$ then $\max(\lceil \log_2 |m| \rceil, 3) + b$ clocks; if $m = 0$ then $3 + b$ clocks. In this formula, m is the multiplier, and
 - $b = 9$ for register to register,
 - $b = 12$ for memory to register,
 - $b = 10$ for register with immediate to register,
 - $b = 11$ for memory with immediate to register.
- e. An Exception may occur, depending on the value of the operand.

f. LOCK is automatically asserted, regardless of the presence or absence of the LOCK prefix.

g. LOCK is asserted during descriptor table accesses.

Notes h through j apply to Am386DE CPU Protected Address Mode only.

- h. Exception 13 fault (General Protection Violation) will occur if the memory operand in CS, DS, ES, FS, or GS cannot be used due to either a segment limit violation or access rights violation. If a stack limit is violated, an Exception 12 (Stack Segment Limit Violation or Not Present) occurs.
- i. For segment load operations, the CPL, RPL, and DPL must agree with the privilege rules to avoid an Exception 13 fault (General Protection Violation). The segment's descriptor must indicate present or Exception 11 (CS, DS, ES, FS, GS Not Present). If the SS register is loaded and a stack segment not present is detected, an Exception 12 (Stack Segment Limit Violation or Not Present) occurs.
- j. All segment descriptor accesses in the GDT or LDT made by this instruction will automatically assert LOCK to maintain descriptor integrity in multiprocessor systems.
- k. JMP, CALL, INT, RET, and IRET instructions referring to another code segment will cause an Exception 13 (General Protection Violation) if an applicable privilege rule is violated.
- l. An Exception 13 fault occurs if CPL is greater than 0 (0 is the most privileged level).
- m. An Exception 13 fault occurs if CPL is greater than IOPL.
- n. The IF bit of the flag register is not updated if CPL is greater than IOPL. The IOPL field of the flag register is updated only if CPL = 0.

- o. The PE bit of the MSW (CR0) cannot be reset by this instruction. Use MOV into CR0 if desiring to reset the PE bit.*
- p. Any violation of privilege rules as applied to the selector operand does not cause a protection Exception; rather, the zero flag is cleared.*
- q. If the coprocessor's memory operand violates a segment limit or segment access rights, an Exception 13 fault (General Protection Exception) will occur before the ESC instruction is executed. An Exception 12 fault (Stack Segment Limit Violation or Not Present) will occur if the stack limit is violated by the operand's starting address.*
- r. The destination of a JMP, CALL, INT, RET, or IRET must be in the defined limit of a code segment or an Exception 13 fault (General Protection Violation) will occur.*

Instruction Encoding

Overview

All instruction encodings are subsets of the general instruction format shown in Figure 71. Instructions consist of one or two primary op-code bytes, possibly an address specifier consisting of the mod r/m byte and scaled index byte, a displacement if required, and an immediate data field if required.

Within the primary op-code or op-codes, smaller encoding fields may be defined. These fields vary according to the class of operation. The fields define such information as direction of the operation, size of the displacements, register encoding, or sign extension.

Almost all instructions referring to an operand in memory have an addressing mode byte following the primary op-code byte(s). This byte, the mod r/m byte, specifies the address mode to be used. Certain encodings of the mod r/m byte indicate a second addressing byte, the scale-index-base byte, follows the mod r/m byte to fully specify the addressing mode.

Addressing modes can include a displacement immediately following the mod r/m byte, or scaled index byte. If a displacement is present, the possible sizes are 8, 16, or 32 bits.

If the instruction specifies an immediate operand, the immediate operand follows any displacement bytes. The immediate operand, if specified, is always the last field of instruction.

Figure 71 illustrates several of the fields that can appear in an instruction, such as the mod field and the r/m field,

but the Figure does not show all fields. Several smaller fields also appear in certain instructions, sometimes within the op-code bytes themselves. Table 25 is a complete list of all fields appearing in the Am386DE microprocessor instruction set.

32-Bit Extensions of the Instruction Set

With the Am386DE microprocessor, the 8086/80186/80286 instruction set is extended in two orthogonal directions: 32-bit forms of all 16-bit instructions are added to support the 32-bit data types, and 32-bit addressing modes are made available for all instructions referencing memory. This orthogonal instruction set extension is accomplished having a Default (D) bit in the code segment descriptor, and by having 2 prefixes to the instruction set.

Whether the instruction defaults to operations of 16 or 32 bits depends on the setting of the D bit in the code segment descriptor, which gives the default length (either 32 or 16 bits) for both operands and effective addresses when executing that code segment. In the Real Address Mode, no code segment descriptors are used, but a D value of 0 is assumed internally by the Am386DE microprocessor when operating in this mode (for 16-bit default sizes compatible with the 8086/80186/80286).

Two prefixes, the Operand Size Prefix and the Effective Address Size Prefix, allow overriding individually the Default selection of operand size and effective address size. These prefixes may precede any op-code bytes and affect only the instruction they precede. If necessary, one or both of the prefixes may be placed before the op-code bytes. The presence of the Operand Size Prefix and the Effective Address Prefix will toggle the operand size or the effective address size, respectively, to the value opposite from the Default setting. For example, if the default operand size is for 32-bit data operations, then presence of the Operand Size Prefix toggles the instruction to 16-bit data operation. As another example, if the default effective address size is 16 bits, presence of the Effective Address Size prefix toggles the instruction to use 32-bit effective address computations.

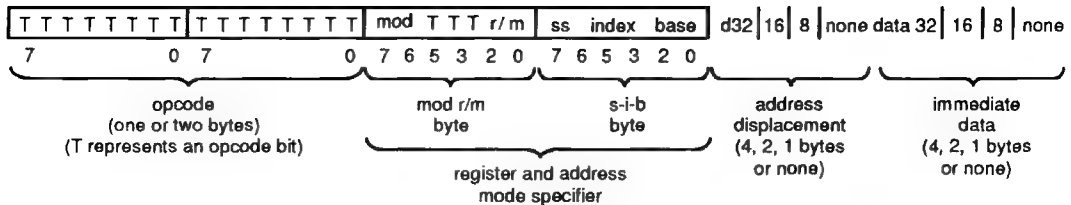


Figure 71. General Instruction Format

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Table 25. Fields within Am386DE Microprocessor Instructions

Field Name	Description	Number of Bits
w	Specifies if Data is Byte or Full Size (Full Size is either 16 or 32 bits)	1
d	Specifies Direction of Data Operation	1
s	Specifies if an Immediate Data Field must be Sign-Extended	1
reg	General Register Specifier	3
mod r/m	Address Mode Specifier (Effective Address can be a General Register)	2 for mod; 3 for r/m
ss	Scale Factor for Scaled Index Address Mode	2
index	General Register to be used as Index Register	3
base	General Register to be used as Base Register	3
sreg2	Segment Register Specifier for CS, SS, DS, ES	2
sreg3	Segment Register Specifier for CS, SS, DS, ES, FS, GS	3
tttn	For Condition Instructions, specifies a Condition Asserted or a Condition Negated	4

Note: Table 23 shows encoding of individual instructions.

These 32-bit extensions are available in all Am386DE microprocessor modes, including the Real Address Mode. In these modes the default is always 16 bits, so prefixes are needed to specify 32-bit operands or addresses. For instructions with more than one prefix, the order of prefixes is unimportant.

Unless specified otherwise, instructions with 8- and 16-bit operands do not affect the contents of the high-order bits of the extended registers.

Encoding of Instruction Fields

Within the instruction are several fields indicating register selection, addressing mode and so on. The exact encodings of these fields are defined immediately ahead.

Encoding of Operand Length (w) Field

For any given instruction performing a data operation, the instruction is executing as a 32- or 16-bit operation. Within the constraints of the operation size, the w field encodes the operand size as either one byte or the full operation size, as shown in the following table.

w Field	Operand Size During 16-Bit Data Operations	Operand Size During 32-Bit Data Operations
0	8 Bits	8 Bits
1	16 Bits	32 Bits

Encoding of General Register (reg) Field

The general register is specified by the reg field, which may appear in the primary op-code bytes, or as the reg field of the mod r/m byte, or as the r/m field of the mod r/m byte.

Encoding of reg Field When w Field Is not Present in Instruction

reg Field	Register Selected During 16-Bit Data Operations	Register Selected During 32-Bit Data Operations
000	AX	EAX
001	CX	ECX
010	DX	EDX
011	BX	EBX
100	SP	ESP
101	BP	EBP
110	SI	ESI
111	DI	EDI

Encoding of reg Field When w Field Is Present in Instruction

Register Specified by reg Field During 16-Bit Data Operations		
reg	Function of w Field	
	(when w = 0)	(when w = 1)
000	AL	AX
001	CL	CX
010	DL	DX
011	BL	BX
100	AH	SP
101	CH	BP
110	DH	SI
111	BH	DI

Register Specified by reg Field During 32-Bit Data Operations		
reg	Function of w Field	
	(when w = 0)	(when w = 1)
000	AL	EAX
001	CL	ECX
010	DL	EDX
011	BL	EBX
100	AH	ESP
101	CH	EBP
110	DH	ESI
111	BH	EDI

Encoding of Segment Register (sreg) Field

The sreg field in certain instructions is a 2-bit field allowing one of the four 80286 segment registers to be specified. The sreg field in other instructions is a 3-bit field, allowing the Am386DE microprocessor FS and GS segment registers to be specified.

2-Bit sreg2 Field

2-Bit sreg2 Field	Segment Register Selected
00	ES
01	CS
10	SS
11	DS

3-Bit sreg3 Field

3-Bit sreg3 Field	Segment Register Selected
000	ES
001	CS
010	SS
011	DS
100	FS
101	GS
110	do not use
111	do not use

Encoding of Address Mode

Except for special instructions, such as PUSH or POP, where the addressing mode is pre-determined, the addressing mode for the current instruction is specified by addressing bytes following the primary op-code. The primary addressing byte is the mod r/m byte, and a second byte of addressing information, the scale-index-base (s-i-b) byte, can be specified.

The s-i-b byte is specified when using 32-bit addressing mode and the mod r/m byte has r/m = 100 and mod = 00, 01, or 10. When the s-i-b byte is present, the 32-bit addressing mode is a function of the mod, ss, index, and base fields.

The primary addressing byte, the mod r/m byte, also contains three bits (shown as TTT in Figure 83) sometimes used as an extension of the primary op-code. The three bits, however, may also be used as a register field (reg).

When calculating an effective address, either 16-bit addressing or 32-bit addressing is used. 16-bit addressing uses 16-bit address components to calculate the effective address while 32-bit addressing uses 32-bit address components to calculate the effective address. When 16-bit addressing is used, the mod r/m byte is interpreted as a 16-bit addressing mode specifier. When 32-bit addressing is used, the mod r/m byte is interpreted as a 32-bit addressing mode specifier.

Tables on the following pages define all encodings of all 16- and 32-bit addressing modes.

Encoding of 16-Bit Address Mode with mod r/m Byte

mod r/m	Effective Address	mod r/m	Effective Address
00 000	DS:[BX + SI]	10 000	DS:[BX + SI + d16]
00 001	DS:[BX + DI]	10 001	DS:[BX + DI + d16]
00 010	SS:[BP + SI]	10 010	SS:[BP + SI + d16]
00 011	DS:[BP + DI]	10 011	SS:[BP + DI + d16]
00 100	DS:[SI]	10 100	DS:[SI + d16]
00 101	DS:[DI]	10 101	DS:[DI + d16]
00 110	DS:d16	10 110	SS:[BP + d16]
00 111	DS:[BX]	10 111	DS:[BX + d16]
01 000	DS:[BX + SI + d8]	11 000	Register— See Below
01 001	DS:[BX + DI + d8]	11 001	Register— See Below
01 010	SS:[BP + SI + d8]	11 010	Register— See Below
01 011	SS:[BP + DI + d8]	11 011	Register— See Below
01 100	DS:[SI + d8]	11 100	Register— See Below
01 101	DS:[DI + d8]	11 101	Register— See Below
01 110	SS:[BP + d8]	11 110	Register— See Below
01 111	DS:[BX + d8]	11 111	Register— See Below

Register Specified by r/m During 32-Bit Data Operations		
mod r/m	Function of w Field	
	(when w = 0)	(when w = 1)
11 000	AL	EAX
11 001	CL	ECX
11 010	DL	EDX
11 011	BL	EBX
11 100	AH	ESP
11 101	CH	EBP
11 110	DH	ESI
11 111	BH	EDI

Register Specified by r/m During 16-Bit Data Operations		
mod r/m	Function of w Field	
	(when w = 0)	(when w = 1)
11 000	AL	AX
11 001	CL	CX
11 010	DL	DX
11 011	BL	BX
11 100	AH	SP
11 101	CH	BP
11 110	DH	SI
11 111	BH	DI

**Encoding of 32-Bit Address Mode with mod r/m byte
(No s-i-b Present)**

mod r/m	Effective Address	mod r/m	Effective Address
00 000	DS:[EAX]	10 000	DS:[EAX + d32]
00 001	DS:[ECX]	10 001	DS:[ECX + d32]
00 010	DS:[EDX]	10 010	DS:[EDX + d32]
00 011	DS:[EBX]	10 011	DS:[EBX + d32]
00 100	s-i-b is present	10 100	s-i-b is present
00 101	DS:d32	10 101	SS:[EBP + d32]
00 110	DS:[ESI]	10 110	DS:[ESI + d32]
00 111	DS:[EDI]	10 111	DS:[EDI + d32]
01 000	DS:[EAX + d8]	11 000	Register— See Below
01 001	DS:[ECX + d8]	11 001	Register— See Below
01 010	DS:[EDX + d8]	11 010	Register— See Below
01 011	DS:[EBX + d8]	11 011	Register— See Below
01 100	s-i-b is present	11 100	Register— See Below
01 101	SS:[EBP + d8]	11 101	Register— See Below
01 110	DS:[ESI + d8]	11 110	Register— See Below
01 111	DS:[EDI + d8]	11 111	Register— See Below

Register Specified by reg or r/m During 32-Bit Data Operations		
mod r/m	Function of w Field	
	(when w = 0)	(when w = 1)
11 000	AL	EAX
11 001	CL	ECX
11 010	DL	EDX
11 011	BL	EBX
11 100	AH	ESP
11 101	CH	EBP
11 110	DH	ESI
11 111	BH	EDI

Register Specified by reg or r/m During 16-Bit Data Operations		
mod r/m	Function of w Field	
	(when w = 0)	(when w = 1)
11 000	AL	AX
11 001	CL	CX
11 010	DL	DX
11 011	BL	BX
11 100	AH	SP
11 101	CH	BP
11 110	DH	SI
11 111	BH	DI

Encoding of 32-Bit Address Mode (mod r/m Byte and s-i-b present)

mod base	Effective Address
00 000	DS:[EAX + (scaled index)]
00 001	DS:[ECX + (scaled index)]
00 010	DS:[EDX + (scaled index)]
00 011	DS:[EBX + (scaled index)]
00 100	SS:[ESP + (scaled index)]
00 101	DS:[d32 + (scaled index)]
00 110	DS:[ESI + (scaled index)]
00 111	DS:[EDI + (scaled index)]
01 000	DS:[EAX + (scaled index) + d8]
01 001	DS:[ECX + (scaled index) + d8]
01 010	DS:[EDX + (scaled index) + d8]
01 011	DS:[EBX + (scaled index) + d8]
01 100	SS:[ESP + (scaled index) + d8]
01 101	SS:[EBP + (scaled index) + d8]
01 110	DS:[ESI + (scaled index) + d8]
01 111	DS:[EDI + (scaled index) + d8]
10 000	DS:[EAX + (scaled index) + d32]
10 001	DS:[ECX + (scaled index) + d32]
10 010	DS:[EDX + (scaled index) + d32]
10 011	DS:[EBX + (scaled index) + d32]
10 100	SS:[ESP + (scaled index) + d32]
10 101	SS:[EBP + (scaled index) + d32]
10 110	DS:[ESI + (scaled index) + d32]
10 111	DS:[EDI + (scaled index) + d32]

Note:

Mod field in mod r/m byte; ss, index, base fields in s-i-b byte.

ss	Scale Factor
00	x1
01	x2
10	x4
11	x8

Index	Index Register
000	EAX
001	ECX
010	EDX
011	EBX
100	no index reg (see note)
101	EBP
110	ESI
111	EDI

Note:

When index field is 100, indicating no index register, then ss field must equal 00. If index is 100 and ss does not equal 00, the effective address is undefined.

Encoding of Operation Direction (d) Field

In many two-operand instructions the d field is present to indicate which operand is considered the source and which is the destination.

d	Direction of Operation
0	Register/Memory ← Register reg Field indicates Source Operand; mod r/m or mod ss index base indicates Destination Operand.
1	Register ← Register Memory reg Field indicates Destination Operand; mod r/m or mod ss index base indicates Source Operand.

Encoding of Sign-Extend (s) Field

The s field occurs primarily to instructions with immediate data fields. The s field has an effect only if the size of the immediate data is 8 bits and is being placed in a 16- or 32-bit destination.

s	Effect on Immediate Data 8	Effect on Immediate Data 16 32
0	None	None
1	Sign-Extended Data 8 to fill 16-Bit or 32-Bit Destination	None

Encoding of Conditional Test (ttn) Field

For the conditional instructions (conditional jumps and set on condition), ttn is encoded with n indicating to use the condition (n=0) or its negation (n=1), and ttt giving the condition to test.

Mnemonic	Condition	ttn
O	Overflow	0000
NO	No Overflow	0001
B/NAE	Below/Not Above or Equal	0010
NB/AE	Not Below/Above or Equal	0011
E/Z	Equal/Zero	0100
NE/NZ	Not Equal/Not Zero	0101
BE/NA	Below or Equal/Not Above	0110
NBE/A	Not Below or Equal/Above	0111
S	Sign	1000
NS	Not Sign	1001
P/PE	Parity/Parity Even	1010
NP/PO	Not Parity/Parity Odd	1011
L/NGE	Less Than/Not Greater or Equal	1100
NL/GE	Not Less Than/Greater or Equal	1101
LE/NG	Less Than or Equal/Not Greater Than	1110
NLE/G	Not Less Than or Equal/Greater Than	1111

Encoding of Control or Debug or Test Register (eee) Field

For the loading and storing of the Control, Debug and Test registers.

When Interpreted as Control Register Field

eee Code	Reg Name
000	CR0
010	CR2
011	CR3
Do not use any other encoding.	

When Interpreted as Debug Register Field

eee Code	Reg Name
000	DR0
001	DR1
010	DR2
011	DR3
110	DR6
111	DR7
Do not use any other encoding.	

When Interpreted as Test Register Field

eee Code	Reg Name
110	TR6
111	TR7
Do not use any other encoding.	

ELECTRICAL DATA

Introduction

The following sections describe recommended electrical connections for the Am386DE microprocessor and its electrical specifications.

Power and Grounding

Power Connections

The Am386DE CPU is implemented in CS21S technology and has modest power requirements. However, its high clock frequency and 72 output buffers (address, data, control, and HLDA) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 20 V_{CC} and 21 V_{SS} pins separately feed functional units of the Am386DE CPU.

Power and ground connections must be made to all external V_{CC} and GND pins of the Am386DE CPU. On the circuit board, all V_{CC} pins must be connected on a V_{CC} plane. All V_{SS} pins must be likewise connected to the GND plane.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the Am386DE CPU. The Am386DE microprocessor driving its 32-bit parallel address and data buses at high frequencies can cause transient power surges, particularly when driving large capacitive loads.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening circuit board traces between the Am386DE microprocessor and decoupling capacitors as much as possible.

Resistor Recommendations

The $\overline{\text{ERROR}}$, $\overline{\text{FLT}}$, and $\overline{\text{BUSY}}$ inputs have resistor pull-ups of approximately 20 Kohms built into the Am386DE CPU to keep these signals negated when no 387DX math coprocessor is present in the system (or temporarily removed from its socket). The $\overline{\text{BS16}}$ input also has an internal pull-up resistor of approximately 20 Kohms, and the $\overline{\text{PEREQ}}$ input has an internal pull-down resistor of approximately 20 Kohms.

In typical designs, the external pull-up resistors are recommended. However, a particular design may have reason to adjust the resistor values recommended here, or alter the use of pull-up resistors in other ways.

Other Connection Recommendations

For reliable operation, always connect unused inputs to an appropriate signal level. NC pins should always remain unconnected.

Particularly when not using interrupts or bus hold, (as when first prototyping, perhaps) prevent any chance of spurious activity by connecting these associated inputs to GND.

Pin	Signal
B7	INTR
B8	NMI
D14	HOLD

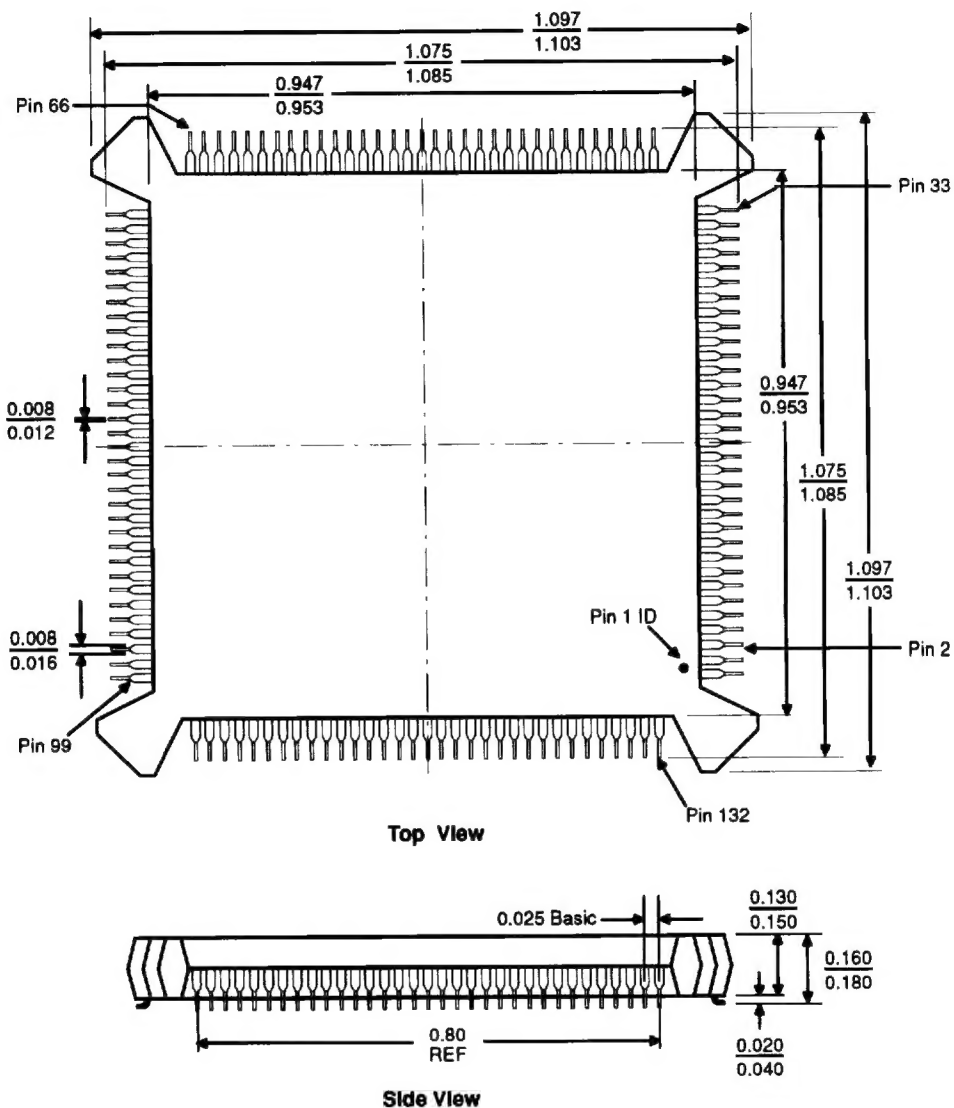
If not using address pipelining, pull-up D13 $\overline{\text{NA}}$ to V_{CC} .

If not using 16-bit size, pull-up C14 $\overline{\text{BS16}}$ to V_{CC} .

Pull-ups in the range of 20 Kohms are recommended.

PHYSICAL DIMENSIONS

PQB 132 – Plastic Quad Flat Pack; Trimmed and Formed
(all measurements are in inches)



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